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(PROFESSIONAL PAPER.)

CONCRETE LINING AS APPLIED TO IRRIGATION CANALS.

By Samuel Fortier, *Chief of Irrigation Investigations.*

INTRODUCTION.

An estimate based on the census of 1910 shows that approximately 74,400,000 acre-feet of water is diverted annually from streams, reservoirs, wells, and other sources of supply in the United States for use in irrigation. If this volume were spread over an area the size of the State of New York it would cover it to a depth of over 28 inches. To convey this amount of water, often from distant sources, and distribute it over cultivated lands require a large number of canals with capacities varying from several thousand second-feet to a part of a second-foot, or a few miner's inches. In the United States, irrigation canals are for the most part excavated in earth, and, except in a few cases, a large percentage of the water, estimated at 40 per cent of the amount taken in at the heads of the main canals, is lost by absorption and percolation along the routes. But allowing for water later recovered by lower conduits, the amount that is wholly lost may be reduced to 25 per cent.

The benefits resulting from work in recent years in the lining of canals for preventing transmission losses have been marked.

This publication presents in a summarized form some results of seepage measurements and discusses the subject of lining canals with concrete as one of the best known means of preventing seepage losses. Most of the irrigation canals in this country that have been lined with concrete have been examined and the good and bad features of each noted. Construction methods have likewise been studied. In brief the main object of the entire investigation has been to show, first, the need of an impervious lining and, second, the best practice to follow in construction work of this kind.

Note.—This bulletin treats of the subject of concrete lining for irrigation canals from the standpoints of economy, design, and construction. It is intended for the use of irrigation engineers and the managers and superintendents of irrigation systems.

UNLINED CANALS.

The census of 1910 showed for that year 81,837 main and lateral ditches, aggregating 125,591 miles in length and having a maximum capacity of 618,097 second-feet. Assuming that not over 4 per cent of the total volume of water used in irrigation was carried in pipes, flumes, and lined canals and deducting all channels having impervious linings, there remained over 120,000 miles of unlined irrigation canals in the West.

Transmission losses in the channels considered herein may be grouped under the headings leakage, evaporation, and seepage. Cheap and faulty structures are a common cause of leakage, but such losses are only a small percentage of the total loss.

A large percentage of the water used to moisten the top layer of soils is evaporated.[1] Water flowing in an open conduit evaporates from the surface an amount dependent upon the temperature of both air and water, the velocity of the wind, and upon other factors. This loss, as in the case of leakage from faulty construction, is so small that it may be neglected without causing appreciable error.

Evaporation data obtained from 37 different stations throughout the various arid States and covering the months of June, July, August, and September give average daily rates in inches for this period as follows: Maximum, 0.34; minimum, 0.18; and mean, 0.26. For practical purposes the loss of water from a canal through evaporation is a negligible quantity.

SEEPAGE LOSSES.

The results of measurements of seepage show that this is the most important source of loss from canals.

As Table I indicates, in many cases full data are not available, particularly as to the character of the materials through which the canals are excavated. The canals measured vary widely in capacity and with one exception are situated in various parts of the arid regions of the United States. About 1,500 miles of separate canal sections are represented in the data collected and considering the character of materials, erosion, age, etc., they cover a wide range of conditions. It must of course be recognized that with measurements taken under such diverse conditions and by the different methods used in collecting these data allowance must be made for probable inaccuracies in the results. It may, and probably does, happen that in cases where the amount of loss or gain is small, the variation may really amount to a gain where it is given as a loss and vice versa depending on the accuracy of the methods used and the care taken in making the measurements for a given canal. However, in collecting these data an effort was made to eliminate all measurements of doubtful accuracy in so far as this could be determined from the records examined.

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[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 248.

Two methods of expressing seepage losses in canals are in common use. One method expresses the loss in the percentage of flow of the canal while the other expresses the loss in 24 hours in terms of cubic feet per square foot of wetted area. Opinions differ as to the relative merits of these methods, but each has its advantages. The former gives one a ready grasp of the efficiency of a canal in a general way while the latter permits a more detailed estimate of the loss which may be expected from a given section of a canal when the conditions therein have been carefully studied. However, seepage losses from canals are governed by many variable and interdependent conditions, the combined influence of which it is very difficult, if not altogether impracticable, to reduce to a mathematical formula. The writer is convinced that no refinement of calculation for estimating seepage losses in proposed canals is warranted at this time without considerable data directly applicable to individual conditions, and even when this is obtainable the accuracy of the estimate will largely depend upon the skill as well as upon the experience and judgment of the estimator.

Seepage measurements made by this office together with the greater part of the reliable records obtainable are combined in Table I.

Table I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
		Miles.	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Arizona.										
Arizona, Salt River	2	6	79.8	.....	36.7	38.0	......	......	4.2	5.26
			93.3	.....	37.1	38.5	......	......	4.5	4.83
Do	1	12	113.0	.....	36.0	37.1	......	......	6.5	5.75
Consolidated, Salt River	3	4	124.6	.....	42.3	43.5	......	......	3.5	2.81
			22.8	.....	39.0	40.2	......	......	2.0	8.78
			53.3	.....	40.0	41.1	......	......	2.8	5.26
California.										
Callison Slough, Tule River	1	2.5	55.0	.....	......	......	......	......	7.0	13.00
Tipton Irrigation District, Tule River.	1	10.0	75.5	.....	......	......	......	......	....	68.00
Do	1	12.0	48.7	.....	......	......	......	......	....	81.00
Fine Ditch, Tule River	2	1.5	21.2	.....	......	......	......	......	3.7	17.00
			31.9	.....	......	......	......	......	7.5	24.00
Vandalia Ditch, Tule River	2	2.00	16.0	.....	......	......	......	......	....	92.00 89.00
	1	1.5	10.2	.....	......	......	......	......	....	96.00
Porter Slough, Tule River	1	2.0	97.6	.....	......	......	......	......	....	1.60
Do	1	4.0	3.7	.....	......	......	......	......	....	46.00
Poplar Ditch, Tule River	3	4.0	35.3	.....	......	......	......	......	....	25.00
			73.3	.....	......	......	......	......	....	13.00
			42.8	.....	......	......	......	......	....	38.00
Do	1	7.75	73.3	.....	......	......	......	......	....	22.00
	1	2.75	26.9	.....	......	......	......	......	....	18.00
	1	3.00	21.9	.....	......	......	......	......	....	23.00
Pleasant Valley, Tule River	1	4.5	4.9	.....	......	......	......	1.0	....	50.00
Do	1	5.0	5.6	.....	......	......	......	......	....	43.00
South Tule Independent Ditch, Tule River.	2	5.0	7.9	.....	......	......	......	......	1.1	14.00
			5.6	.....	......	......	......	......	.7	12.50
Modesto, Tuolumne River	1	33.0	260.0	.....	......	......	......	......	56.1	21.50
Do	1	22.0	532.0	.....	......	......	......	......	....	6.60
Do	1	18.0	793.0	.....	......	......	......	......	....	3.06
Turlock, Tuolumne River	1	22.0	879.0	.....	......	......	......	......	....	4.40
Birch Lateral, Colorado River	1	4.0	17.75	.....	......	......	......	......	....	1.00
Do	1	3.0	24.45	.....	......	......	......	......	.59	2.40
Beach Lateral, Colorado River	1	6.5	7.12	.....	......	......	......	......	2.75	38.60

measurements.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
0.88	0.80	0.84	0.30 .32		Report W. H. Code, O. E. S. Bul. 104, Sep. No. 2, 1900.	Channel coated with an almost impervious silt deposit.
		.48	.23		do	Do.
2.19	.70	1.40	.33		do	Do.
			.20		do	Do.
			.28		do	Do.
		5.20			Report A. E. Chandler, O. E. S. Bul. 119, Sep. No. 2, 1901.	
		6.80			do	First use in 5 years. Gopher and squirrel holes in channel bed.
		6.75			do	Do.
16.00	11.30	13.60			do	
46.00	44.50	45.25				
		64.00		See remarks	Report A. E. Chandler, O. E. S. Bul. 119, Sep. No. 2, 1901.	Channel through sand of the first river bench.
		.80			do	Discharge (97.6) measured at headgate June 1, 1901.
		11.50			do	Discharge (3.7) measured at headgate July 9, 1901.
9.50	3.25	6.33				Measured June 12, 1901, at the head of canal. Measured June 14, 1901, at the head of canal. Measured June 27, 1901, at the head of canal.
		9.46			Report A. E. Chandler, O. E. S. Bul. 119, Sep. No. 2, 1901.	Measured June 14, 1901, at the head of canal.
		6.55			do	Measured June 29, 1901, 4 miles below head of canal.
		7.66			do	Measured June 29, 1901, at the head of a lateral.
		11.10			do	
		8.60			do	
2.80	2.50	2.65			do	Measured at head. For first 4½ miles bottom width 5 feet, grade 8 feet per mile. The succeeding ½ mile bottom width 6 feet, grade 6 feet per mile.
		.65			Report Frank Adams, O. E. S. Bul. 158, Sep. No. 3, 1904.	See O. E. S. Bul. 158, Sep. No. 3, for losses in individual portions of canal.
		.30			Report Frank Adams, O. E. S. Cir. 108, 1909.	
		.17			do	
		.20			do	
		5.63			Report J. E. Roadhouse, O. E. S. Bul. 158, Sep. No. 3, 1904.	Measured June 16, 1903.
1.41	.80	1.10				Measured June 23, 1903.
		5.90		Sandy, weedy, and flat; 2 miles in embankment.	do	

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
California—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Dahlia Lateral, Colorado River	1	9.5	45.40	......	......	......	......	......	8.95	19.70
Dogwood Lateral, Colorado River	1	6.0	22.60	......	......	......	......	......	5.72	25.30
Holt Lateral, Colorado River	1	5.0	27.3	......	......	......	......	......	2.84	10.00
Do	1	3.5	12.9	......	......	......	......	......	1.10	8.51
Rose Lateral, Colorado River	1	6.0	36.5	......	......	......	......	......	4.54	12.40
Do	1	4.75	24.5	......	......	......	......	......	1.22	4.97
Moore Ditch, main canal, Cache Creek.	2	.8	115.6	......	......	......	......	......	8.73	7.50
			86.5	......	......	......	......	......	5.36	6.20
Do	2	4.0	112.9	......	......	......	......	......	4.26	3.80
			116.3	......	......	......	......	......	4.62	4.00
Do	2	4.0	126.7	......	......	......	......	......	20.9	16.50
			62.6	......	......	......	......	......	12.5	20.00
East Fork or Rumsey Ditch, Lateral of Moore Ditch.	2	3.5	108.4	......	......	......	......	......	34.4	29.90
			44.1	......	......	......	......	......	8.83	20.00
West Fork or Montgomery Ditch, Lateral of Moore Ditch.	1	5.0	65.9	......	......	......	......	......	41.4	62.80
Hoy Ditch, Lateral of Moore Ditch	1	3.0	35.42	......	......	......	......	......	14.58	41.20
Do	1	.5	20.66	......	......	......	......	......	.82	4.00
Stringtown Lane, Lateral of Moore Ditch.	1	2.0	24.69	......	......	......	......	......	7.68	31.10
Do	1	.5	17.01	......	......	......	......	......	4.60	27.00
South Fork, Lateral of Moore Ditch.	1	1.0	29.93	......	......	......	......	......	4.92	16.40
Schoolhouse, Lateral of Moore Ditch.	1	2.0	30.40	......	......	......	......	......	15.09	49.70
Capay-Winters, Cache Creek	1	3.0	78.8	......	......	......	......	......	36.1	45.80
Do	1	15.5	42.7	......	......	......	......	......	7.2	16.80
Do	1	11.5	38.8	......	......	......	......	......	12.9	33.30
Central, Sacramento River	1	11.0	......	......	......	......	......	......	......	37.00
Stony Creek Irrigation Co., Stony Creek.	11	[2] 0.40–8.20	[3] 16.6–80	......	......	......	......	......	......	......
San Joaquin and Kings River, San Joaquin River.	...	5.0	190–239	......	......	......	......	......	......	......
Kings River and Fresno, Kings River.	1	3.55	55.7	......	......	......	......	39.6	4.4	8.00
Do	1	4.75	80.4	......	......	......	......	8.2	16.5	20.50
Do	1	12.0	133.8	......	......	......	......	10.1	43.4	32.40

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[1] Farmers' laterals foul with weeds, many gopher holes, and diversion weirs out of repair caused many leaks.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	2.07	....	First one-half in slight cut with remainder somewhat silted, especially in last 2 miles.	Report J. E. Roadhouse, O. E. S. Bul. 158, Sep. No. 3, 1904.	Measured June 7, 1903.
......	......	4.22	....	Lateral was in poor condition; deposit of silt inside; levees partially weedy.	.....do.............	Measured July 8, 1903.
2.43	2.00	2.22	....	Soil varied with strata of silt and clay.	....do.............	Measured in 1903.
2.07	1.05	......	....	....	.....do.............	Do.
......	......	9.40	....	Canal in gravelly creek bed.	Report Samuel Fortier, O. E. S. Bul. 207, 1909.	Measured July 31, 1906.
......	......	7.80	....	....	.....do.............	Measured Sept. 8, 1906.
......	......	.90	....	Heavy clay loam, puddled by domestic animals.	....do.............	Measured Aug. 1, 1906.
......	......	1.00	....	.....do................	.....do.............	Measured July 25, 1906.
......	......	4.10	....	Same section, but much less puddling.	....do.............	Measured July 10, 1907.
......	......	5.00	....	.....do................	.....do.............	Measured July 30, 1907.
......	......	8.50	....	....	.....do.............	Measured July 26, 1906.
......	......	5.70	....	....	.....do.............	Measured Sept. 8, 1906.
......	......	12.60	....	In an open gravelly soil, apparently former bed of Cache Creek.	.....do.............	Measured July 19, 1906.
......	......	13.70	....	....	.....do.............	Measured Aug. 11, 1906.
......	......	8.00	....	....	.....do.............	Measured July 5, 1906.
......	......	15.50	....	....	.....do.............	Measured July 17, 1906.[1]
......	......	54.00	....	....	.....do.............	Measured July 5, 1906.[1]
......	......	16.40	....	....	.....do.............	Measured July 24, 1906.[1]
......	......	24.80	....	....	.....do.............	Measured July 5, 1906.[1]
......	......	15.30	....	Canal in old creek bed of wash gravel.	.....do.............	Measured Aug. 9, 1907.
......	......	1.10	....	Clay loam..........	.....do.............	Measured Aug. 9, 1907. Tight diversion weirs.
......	......	2.90	....	.....do................	.....do.............	Measured Aug. 11, 1907, from Winters to State Farm, Davis.
......	......	3.40	....	.....do................	.....do.............	Measured in 1907. Flowing about 100 second-feet at upper end of section; canal designed to carry 8 times this capacity.
8.65	1.06	3.80	....	.....do................	.....do.............	
......	......	.45	....	....	Report Frank Adams, O. E. S. Cir. 108, 1911.	Measured in 1908.
4.32	2.25	3.09	....	Light sandy loam....	Report C. E. Grunsky, U. S. G. S. Water-Supply Paper No. 18, 1898.	Measured in 1882.
			....	Indurated clay hardpan below surface soil.	....do.............	Do.
			....	Hardpan bed........	.....do.............	Do.

[2] Average, 4.06.

[3] Average, 40.8.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
California—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Fresno, Kings River	1	4.0	60.4	......	......	......	......	28.0	3.8	6.30
Do	1	7.0	139.1	......	......	......	......	73.5	5.2	3.70
Do	1	11.25	381.0	......	......	......	......	146.4	95.5	25.00
Centerville and Kingsburg, Kings River.	1	1.0	251	......	......	......	......	26.7	52.3	20.80
Do	1	5.5	346	......	......	......	......	9.1	85.9	24.80
Small ditches	1	1.0	2.41	......	......	......	......	......	1.42	59.00
Do	1	.5	1.70	......	......	......	......	......	.79	44.00
Lateral of Fresno Canal	1	4.0	5.6	......	......	......	......	......	4.38	78.20
Kern County, Kern River	....	General.	......	......	......	......	......	......	......	......
Colorado.										
Grand, Grand River	1	4.75	337.0	......	......	......	......	86.1	[1] 9.60	[1] 2.84
Do	1	2.25	260.5	......	......	......	......	11.3	8.70	3.34
High line, Grand River	1	5.0	139.6	......	......	......	......	18.1	5.05	3.62
Do	1	1.25	116.5	......	......	......	......	8.55	.94	.81
Do	1	6.75	106.98	......	......	......	......	34.31	1.48	1.38
Do	1	4.75	79.63	......	......	......	......	20.82	12.9	8.64
Do	1	3.5	55.9	......	......	......	......	12.42	.99	1.77
Lake, Arkansas River	1	16.0	456.3	......	......	......	......	249.4	35.6	7.80
Pleasant Valley and Lake, Cache la Poudre.	1	1.30	22.1	......	......	......	......	.16	4.70	21.30
Do	1	1.31	17.23	......	......	......	......	.69	5.90	34.2
Do	1	.82	7.17	......	......	......	......	......	.88	12.3
Do	1	.72	6.29	......	......	......	......	......	.64	10.2
Do	1	.30	6.41	......	......	......	......	......	1.87	29.3
Do	1	2.55	13.42	......	......	......	......	6.19	[1] 4.50	[1] 33.5
Do	1	2.64	13.02	......	......	......	......	2.82	.25	1.92

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[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foo tof wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
2.20	0.53	1.43	....	Natural channel; ground water 4 to 10 feet.	Report C. E. Grunsky, U. S. G. S. Water-Supply Paper No. 18, 1898.	Measured in 1882. Artificial channel of uniform dimensions.
			....	.....do............	.....do............	Measured in 1882. Surface soil and subsoils saturated.
			....	.....do............	.....do............	Measured in 1882.
20.80	4.50	......	6.0	Porous soil and subsoil.	....do............	Do.
			6.0	.....do............	Also Bul. 48, Colo. Expt. Sta. 1898.	Do.
......	......	59.00	1.2–6.4	Sandy loam 5 to 8 feet deep.	Report C. E. Grunsky, U. S. G. S. Water-Supply Paper No. 18, 1898; also Bul. 48, Colo. Expt. Sta., 1898.	Measured June 14, 1882, on Gould ranch north of Fresno. Average width, 3 feet; shade trees along portion of ditch, and banks overgrown with grass; weir used.
......	......	88.00	1.2–6.4	Sandy loam with ground water at 8 feet below surface.	.....do............	Measured June 21, 1882. Lateral of main supply canal; about 2 feet wide; weir used.
......	......	19.50	1.2–6.4	....	.....do............	Measured June 26, 1882. Diverts water from Fresno Canal at point 4 miles east of Fresno. Average width, 8 feet.
......	......	......	.39–2.60	....	....	
......	......	[1].60	....	Heavy clay; all earth.	Report A. P. Stover, O. E. S. Bul. 119, Sep. No. 3, 1901.	31 diversions in this length. Increase thought to come from irrigated lands west of Palisade.[2]
......	......	1.49	....	In shale hills........	.....do............	At numerous places small trickling streams could be seen issuing from canal bank.[2]
......	......	.72	....	Earth............	.....do............	Water section entirely in excavation; considerable sidehill.
......	......	.65	....	.....do............	.....do............	Same as foregoing but mostly along sidehill.
......	......	.21	....	.....do............	.....do............	Comparatively level cross slopes.
......	......	.77	....	.....do............	.....do............	Comparatively level cross slopes; in excellent condition.
......	......	.51	....	.....do............	.....do............	
......	......	.49	....	Sandy loam.........	.....do............	Receives heavily laden silt waters, flood time only. Canal follows river for 11 miles.
......	......	16.40	....	Gravelly and sandy; near river.	Report L. G. Carpenter, Bul. 48, Colo. Expt. Sta., 1898.	
......	......	26.10	....	.....do............	.....do............	
......	......	15.00	....	Stratified slope; rocks inclining.	.....do............	
......	......	14.10	....	.....do............	.....do............	
......	......	......	....	Along outer side ridge near junction of earth and rock.	.....do............	
......	......	[1]13.20	....	....	.....do............	Some land irrigated above ditch from Dixon Canyon.
......	......	.73	....	Somewhat gravelly..	.....do............	Some land irrigated above ditch from Spring Canyon.

[2] Combining these two measurements shows gain greater than loss.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Colorado—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
North farm lateral of Rio Grande Canal, Rio Grande.	2	9.0	90.5	0.88	20.7	......	......	64.3	5.3	5.90
			199.5	1.20	26.0	......	......	156.5	12.5	6.30
Lateral 1C, Rio Grande	1	.5	18.8	.72	13.0	......	......	......	[1] 2.38	[1] 12.70
Do	1	3.0	21.2	......	......	......	......	7.56	6.31	29.70
Prairie, Rio Grande	1	3.5	36.4	......	......	......	......	2.33	[1] 1.42	[1] 3.90
Do	1	1.5	35.5	......	......	......	......	1.92	1.80	5.07
Do	1	4.0	31.9	......	......	......	......	2.81	[1] 3.18	[1] 9.97
Do	1	1.0	29.6	......	......	......	......	......	1.80	6.08
Blackmore, Rio Grande	1	2.03	11.54	......	......	......	......	1.16	3.60	31.20
Empire, Rio Grande	1	5.0	125.0	......	......	......	......	5.02	[1] 16.0	[1] 12.80
Lateral 1F, Rio Grande	1	4.0	12.93	......	......	......	......	2.43	1.68	13.00
Do	1	1.0	8.82	......	......	......	......	2.22	[1] 1.24	[1] 14.00
Lateral of North Poudre Land & Canal Co., South Platte River.	....	4.0	4.49	......	......	......	......	......	.80	20.90
Idaho.										
South Side Twin Falls, Snake River.	1	8.0	900	......	......	......	......	......	64.0	7.10
Lateral of South Side Twin Falls, Snake River.	1	2.+	5.05	......	......	......	......	......	.25	4.95
Do	1	1.0	24.8	......	......	......	......	......	5.6	22.60
Howell & Swendson, Lost River	1	4.0	6.9	......	......	......	......	......	1.7	25.00
Frank Uehren, Lost River	1	.5	1.6	......	......	......	......	......	.3	19.00
Bradshaw, Lost River	1	3.0	5.5	......	......	......	......	......	2.8	51.00
Davidson, Lost River	1	12.0	7.4	......	......	......	......	......	4.6	62.00
Mower, Warm Spring Creek	1	3.0	4.1	......	......	......	......	......	.8	20.00
Sharpe No. 1, Lost River	1	1.0	19	......	......	......	......	......	1.0	5.30
West side (No. 22), Lost River	1	3.5	18.7	......	......	......	......	......	2.7	14.50
Upper Harger (part of No. 23), Lost River.	1	4.0	5.8	......	......	......	......	......	1.7	29.30
Do	1	1.0	4.0	......	......	......	......	......	1.0	25.00
Lower Harger (part of No. 23), Lost River.	1	1.0	11.9	......	......	......	......	......	3.6	30.00
Do	1	3.0	8.75	......	......	......	......	......	.7	8.00
Lateral of Upper Harger, Lost River	1	1.0	2.5	......	......	......	......	......	.2	8.00
Darnley (No. 24), Lost River	1	.25	6.9	......	......	......	......	......	.35	5.00
Do	1	4.0	6.9	......	......	......	......	......	2.4	35.00
Pierce-Keogh, Raft River	1	1.0	4.76	......	......	......	......	......	.66	13.90
Do	1	1.0	4.1	......	......	......	......	......	.14	3.40

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[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	0.65	0.51	Gravelly soil	Report L. G. Carpenter, Bul. 48, Colo. Expt. Sta., 1898.	Individual measurements show variations of 8.47 per cent gain to 8.95 per cent loss.
......	......	.70	.73	do	do	Individual measurements show variations of 8.77 per cent gain to 12.18 per cent loss.
......	......	[1]25.30	....	....	do	Measured Aug. 2, 1897. Lateral of Rio Grande Canal system.
......	......	9.92	....	....	....	
......	......	[1]1.11	....	....	do	Measured July 13, 1897.[2]
......	......	3.38	....	....	do	Do.[2]
......	......	[1]2.49	....	....	do	Measured July 14, 1897.[2]
......	......	6.08	....	....	do	Do.[2]
......	......	15.36	....	....	do	Measured June 17, 1897.
......	......	[1]2.56	....	....	do	Measured June 11, 1897.
......	......	3.25	....	....	do	Measured Aug. 4, 1897. Individual measurements show variations of 5.07 to 0.24 per cent per mile.
......	......	[1]14.00	....	....	do	Measured Aug. 4, 1897. Lateral 1F part of Rio Grande Canal system.
......	......	5.23	....	Mostly clay	do	Measured 1893-1894. Average for two seasons' consecutive run.
......	......	.89	....	Deep soil	Report H. G. Raschbacher, O. E. S. Cir. 65, 1905.	
......	......	2.47	....	Silted	do	Usual grade.
......	......	22.60	....	....	do	Double usual grade. High velocity prevented silting. This measurement and preceding on different laterals.
......	......	6.25	....	Gravel	Report A. E. Wright, O. E. S. Cir. 58, 1903.	Grade excessive.
......	......	38.00	....	do	do	
......	......	17.00	....	do	do	Grade very excessive.
......	......	5.20	....	do	do	Grade moderate. Loss mostly in first mile.
......	......	6.50	....	....	do	Grade excessive.
......	......	5.30	....	....	do	Do.
......	......	4.10	....	....	do	
......	......	7.30	....	....	do	Carrying only one-fourth capacity; even grade and good alignment.
......	......	25.00	....	....	do	Do.
......	......	30.00	....	....	do	Even grade and good alignment.
......	......	2.66	....	....	do	Do.
......	......	8.00	....	....	do	Grade very steep, channel badly eroded in places.
......	......	20.00	....	....	do	
......	......	8.75	....	....	....	
......	......	13.90	....	Very sandy	Report W. F. Bartlett, O. E. S. Bul. 158, Sep. No. 4, 1904.	
......	......	3.40	....	Lined with soft, fine mud about 0.3 foot deep.		

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[2] Measurements taken on abutting sections and given in order.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
South Side Twin Falls, main canal, Snake River.	2	7.79	972	5.0	102.3	......	......	......	91.7	9.40
			1,691	7.9	111.6	......	......	1.3	194.7	11.50
Do	1	......	892	.....	......	......	......	1.8	51.0	5.71
Do	1	11.98	839.4	5.3	92.05	......	......	53.7	101.5	12.10
Do	1	8.07	1,448	6.5	96.4	......	......	14.49	121	8.36
Do	1	6.32	1,312	6.6	96.4	......	......	137	93.9	7.15
Do	1	5.35	2,737	7.53	104.0	110.5	3.43	......	93.0	3.40
Do	1	6.070	2,798.0	7.72	107.3	114.30	3.33	......	30.4	1.10
Do	1	2.650	2,857.0	7.73	107.5	114.0	3.42	......	27.0	.95
Do	1	......	2,934.0	.....	......	......	......	......	54.0	1.80
Do	1	5.050	3,097.0	8.09	118.0	123.0	3.16	......	148.0	4.80
Do	1	3.350	3,192.0	8.00	123.0	129.0	3.16	......	167.0	5.20
South Side Twin Falls, low line, Snake River.	1	6.40	343.1	3.6	54.85	......	......	37.1	34.8	10.10
Do	1	9.61	332.2	3.3	52.2	......	......	147.6	50.7	15.30
Do	1	6.24	133.9	1.8	37.9	......	......	77.2	22.4	16.70

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.21	1.88	Soil deep and slightly sandy. Numerous rock cuts.	Report Elias Nelson, Idaho Expt. Sta. Bul. 58, May, 1907.	Measured June 9, 1906, Milner to Dry Creek Reservoir.
......	......	1.48	3.66	....do..........	....do..........	Measured Aug. 6, 1906, Milner to Dry Creek Reservoir.
......	......	......	.15	Bottom becoming silted.	.....do..........	Measured June 11, 1906, Dry Creek Reservoir only.
......	......	1.01	1.50	Mostly soil; few rock cuts.	.....do..........	Measured June 12, 1906, Dry Creek Reservoir to within 3¼ miles of end of canal.
......	......	1.03	2.54	Mostly soil; few rock cuts near lower end.	.....do..........	Measured Aug. 6, 1906. Includes upper 8.07 miles of preceding measurement; Dry Creek Reservoir to spillway.
......	......	1.13	2.51	....	.....do..........	Measured Aug. 8, 1906, spillway to near end of canal. Backwater condition in lower end of section.
......	......	.60	2.56	Deep uniform clay loam.	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911-12.	Measured July 20, 1912; from Low Line Canal to point 5.35 miles above. Good lower bank; comparatively clean uniform cross section and grade; used 7 years.
......	......	.20	.72	.....do..........	.....do..........	Measured July 18, 1912, from "The Point" to 2.7 miles below Dry Creek Reservoir. Good lower bank; clean uniform cross section; used 7 years.
......	......	.40	1.46	.....do..........	.....do..........	Measured July 18, 1912, the first 2.65 miles below Dry Creek Reservoir. Good lower bank; clean uniform cross section; used 7 years.
......	......	......	....	.....do..........	.....do..........	Measured July 15, 1912; Dry Creek Reservoir only.
......	......	.90	3.905	Deep uniform clay loam with some rock cuts.	.....do..........	Measured July 15, 1912. Upper end of section is 3½ miles below Milner. Banks somewhat eroded; upper bank gone in places; numerous pools above upper bank; used 7 years.
......	......	1.60	6.338	Uniform clay loam with numerous rock cuts.	.....do..........	Measured July 14, 1912. Upper end of section is at Milner wagon bridge. Banks badly eroded; numerous pools above upper bank; no surface indication of seepage; used 7 years.
......	......	1.580	1.62	Heavier than along main canal. Some rock cuts.	Report Elias Nelson, Idaho Expt. Sta. Bul. 58, May, 1907.	Measured June 15, 1907, stations 359 to 697. Waste water (6.8 second-feet) in addition to inflow; first used June, 1905.
......	......	1.590	1.65	.....do..........	.....do..........	Measured June 18, 1907, stations 697 to 1204½. First used, upper part, June, 1905; lower part, April, 1906.
......	......	2.680	1.48	.....do..........	.....do..........	Measured June 19, 1907, stations 697 to 1534.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
South Side Twin Falls, high line Snake River.	1	12.68	226.5	2.9	48.5	......	......	13.34	35.2	15.50
Do	1	16.94	177.9	2.7	41.15	......	......	41.4	44.4	25.00
Do	1	11.8	92.1	1.9	28.4	......	......	45.4	16.8	18.20
Do	1	2.180	759.6	4.94	53.5	57.00	2.88	......	[1] 4.01	1.53
Do	1	2.260	783.0	5.07	56.7	61.40	2.70	......	10.35	1.72
Do	1	2.140	788.4	5.48	53.0	58.90	2.74	......	[1] 12.68	[1] 1.61
Do	1	2.060	832.0	5.55	57.0	62.60	2.61	......	11.1	1.33
Do	1	2.940	877.0	5.31	60.0	64.80	2.72	......	20.9	2.38
South Side Twin Falls, farm lateral, Snake River.	1	.490	.073	.13	.9	1.03	.55	......	.017	23.30
Do	1	.700	.205	.14	1.4	1.51	.97	......	.040	19.50
Do	1	.714	.532	.32	1.5	1.87	1.04	......	.068	12.70
Do	1	.740	.545	.28	1.0	1.35	1.82	......	.070	12.80

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[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.220	0.93	Some gravel and some white lime. See reference.	Report Elias Nelson, Idaho Expt. Sta. Bul. 58, May, 1907.	Measured July 2, 1907, from end of main canal to Cottonwood Creek.
......	......	1.470	1.05	....	.....do..............	Measured July 3, 1907, Cotwood Creek to Cedar draw. First season.
......	......	1.540	.82	....	.....do..............	Measured July 6, 1907, Cedar draw to near end of canal. First season.
......	......	[1] .24	[1] .53	Compact gravel for ½ mile on either side of McMullin Creek; compact clay loam in other places.	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911–12.	Measured July 26, 1912, from 1 mile above McMullin Creek to Cottonwood flume. Banks solid; uniform grade and cross section; porous irrigated land above; used 7 years.
......	......	.76	1.22	Compact gravel mixed with dense clay loam not so gravelly as preceding section.	.....do..............	Measured July 26, 1912, from 1½ miles below Rock Creek to 1 mile above McMullin Creek. Banks solid and well above water line; uniform grade and cross section; used 7 years.
......	......	[1] .75	[1] 1.65	Compact gravel and clay loam, mixed with gravel.	.....do..............	Measured July 26, 1912, from ½ mile above to 1½ miles below Rock Creek crossing. Banks very solid and well made; uniform grade and cross section; porous irrigated land above; used 7 years.
......	......	.65	1.41	Deep uniform clay loam.	.....do..............	Measured July 25, 1912, from station 180+30 to within ½ mile of Rock Creek crossing. Banks well above water line; uniform grade and clean uniform cross section; used 7 years.
......	......	.81	1.79	.....do..............	.....do..............	Measured July 26, 1912, from ½ mile below Low Line Canal to station 180+30. Banks well above water line; uniform grade and clean uniform cross section; used 7 years.
......	......	48.00	.56	Medium clay loam, some surface rock on top of ground.	.....do..............	Measured Sept. 10, 1912, 1 mile south of Twin Falls. Banks irregular; some grass and weeds; used 5 years.
......	......	28.30	.63	Deep medium clay loam.	.....do..............	Measured Sept. 14, 1912, 4 miles northwest of Twin Falls. Irregular cross section; badly eroded; some grass and weeds; used 4 years.
......	......	17.80	.83	Medium clay loam, hardpan near surface.	.....do..............	Measured Sept. 11, 1912, 7 miles southwest of Twin Falls. Irregular cross section; banks eroded; sweet clover in lower half of ditch section.
......	......	17.40	1.15	Deep medium clay loam.	.....do..............	Measured Sept. 13, 1912, 2 miles northeast of Filer. Sodded banks; moss in water; uniform cross section; water in ditch above normal surface of ground; used 4 years.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
South Side Twin Falls, farm lateral, Snake River.	1	0.528	0.802	0.22	1.9	2.11	1.73	......	0.126	15.70
Do	1	.422	.837	.23	1.5	1.72	2.32	......	.030	3.60
Do	1	.573	.871	.28	1.3	1.62	2.35	......	.045	5.20
Do	1	.480	1.12	.29	1.8	2.11	2.04	......	.104	9.30
Do	1	.945	2.03	.34	2.4	2.82	2.31	......	.265	13.10
Do	1	.659	2.22	.38	2.4	2.83	2.40	......	.055	2.50
North Side Twin Falls lateral, Snake River.	1	2.612	14.71	.63	11.1	12.00	1.83	......	3.48	23.60
Do	1	1.936	24.05	.81	20.4	21.38	1.30	......	5.00	20.80
Farm lateral, Snake River	1	.662	1.91	.86	3.0	4.05	.67	......	.37	19.40
Do	1	.498	5.45	.92	3.9	5.53	1.39	......	.96	17.70
Do	1	.584	6.15	.92	4.6	5.83	1.34	......	.46	7.50
Lateral of Burgess Canal, Snake River.	1	.520	8.94	.83	7.5	8.03	1.36	......	.85	9.50

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	29.80	1.84	Medium clay loam...	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911-12.	Measured Sept. 13, 1912, 4 miles southeast of Twin Falls. Regular cross section; somewhat eroded; no weeds; used 5 years.
......	......	8.50	.68	.....do...............	.....do...............	Measured Sept. 12, 1912, 7½ miles southwest of Twin Falls. Clean clover sod on banks; uniform cross section; used 3 years.
......	......	8.90	.79	Deep medium clay loam.	.....do...............	Measured Sept. 9, 1912, 2 miles west of Filer. Clean uniform cross section; used 4 years.
......	......	19.20	1.68	Rather porous clay loam, hardpan at 3 feet.	.....do...............	Measured Sept. 12, 1912, 7 miles southwest of Twin Falls. Uneven cross section; much moss; water near top of bank; used 4 years.
......	......	13.80	1.63	Deep uniform clay loam, hardpan at 2 to 2½ feet.	.....do...............	Measured Sept. 14, 1912, 6½ miles southwest of Twin Falls. Uniform cross section; 1,000 feet new dike; used 5 years.
......	......	3.80	.49	Medium clay loam, hardpan at 2 feet.	.....do...............	Measured Sept. 11, 1912, 6 miles southwest of Twin Falls. Upper part fairly uniform cross section; lower part somewhat irregular, with weeds; used 5 years.
......	......	9.00	1.81	Deep uniform sandy loam.	.....do...............	Measured June 6, 1912, 2 miles east of Wendell. Carrying only half capacity; clean uniform cross section; used 4 years.
......	......	10.70	1.98	Sandy loam.........	.....do...............	Measured June 6, 1912, 1 mile south of Wendell. Clean uniform cross section; no erosion; carrying only one-fourth capacity; used 3 years.
......	......	29.30	2.23	Gravelly, sandy loam	.....do...............	Measured Aug. 26, 1912, 5 miles southwest of Rigby. Partly in dike; fairly uniform cross section; alfalfa, moss and sweet clover growing in channel; used 5 years.
......	......	35.40	5.69	Very gravelly and porous.	.....do...............	Measured Aug. 25, 1912, 4 miles southwest of Rigby. Uniform cross section; heavy growth of weeds and moss in channel; low velocity; used 6 years.
......	......	12.70	2.2	Very gravelly........	.....do...............	Measured Aug. 25, 1912, 4½ miles southwest of Rigby. Irregular cross section; some weeds and sweet clover growing in channel; used 6 years.
......	......	18.20	3.33	Medium gravelly....	.....do...............	Measured Aug. 24, 1912, 7 miles southwest of Rigby. Uniform cross section some gopher holes in bank used 7 years.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Lateral of Burgess Canal, Snake River.	1	1.255	12.52	1.42	7.2	9.20	1.14	......	1.57	12.50
Do	1	.674	18.54	1.35	8.6	9.88	1.54	......	1.35	7.30
Vance, Snake River	1	3.171	41.07	1.46	8.9	11.25	2.98	......	4.84	11.80
Randall, Snake River	1	2.833	135.7	2.49	17.0	21.00	3.10	......	9.36	6.90
Salmon River project, farm lateral, Salmon River.	1	.399	.145	.16	1.0	1.17	.84	......	.015	10.30
Do	1	.378	.575	.15	1.5	1.62	2.49	......	.033	5.70
Do	1	.519	.987	.27	3.5	3.72	.99	......	.068	6.90
Do	1	.351	1.28	.29	2.0	2.30	2.19	......	.011	.90
Do	1	.554	2.18	.31	3.0	3.30	2.34	......	.049	2.30
Do	1	.576	2.26	.42	2.5	2.98	2.03	......	.099	4.40
Salmon River project, main canal, Salmon River.	1	2.928	78.6	1.29	45.0	46.25	1.30	......	5.88	7.50

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	9.90	2.22	Medium gravelly....	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911–12.	Measured Aug. 24, 1912, 4½ miles southwest of Rigby. Uniform cross section; partly in dike; weeds and sweet clover growing in ditch; used 7 years.
......	......	10.80	3.32	.....do..............	.....do..............	Measured Aug. 23, 1912, 7 miles southwest of Rigby. Uniform cross section; carrying about one-half capacity; clean channel; uniform velocity; used 6 years.
......	......	3.70	2.28	Gravelly............	.....do..............	Measured Aug. 17, 1912, 4½ miles southwest of Rigby. Irregular grade and cross section; moss and roots in channel; used 8 years.
......	......	2.40	2.58	Sand and gravel.....	.....do..............	Measured Aug. 16, 1912, 6 miles southeast of Rigby. Uniform grade and cross section; growth moss and weeds in channnel and on banks; used 8 years.
......	......	25.90	.55	Medium clay loam...	.....do...	Measured June 20, 1912, 1½ miles east of Hollister. Banks fairly regular; bottom fairly well silted; used 1 year.
......	......	15.20	.88	Shallow clay loam, hardpan at 1½ feet.	.....do..............	Measured June 19, 1912, ½ mile east of Hollister. Irregular cross section; bottom silted in places; other places hardpan exposed; used 1 year.
......	......	13.30	.68	Clay loam underlain with hardpan at 1½ feet.	.....do..............	Measured June 20, 1912, 1¼ miles east of Hollister. Clean, uniform cross section; hardpan exposed; used 2 years.
......	......	2.50	.23	Clay loam...........	.....do..............	Measured June 21, 1912, 2 miles east of Hollister. Clean, uniform cross section; used 2 years.
......	......	4.00	.43	Shallow clay loam...	.....do..............	Measured June 18, 1912, 1½ miles southwest of Hollister. Clean but somewhat irregular cross section; ditch across nonirrigated sagebrush lands; used 1 year.
......	......	7.60	.95	Medium clay loam, hardpan at 2½ feet.	.....do..............	Measured June 19, 1912, 2 miles south of Hollister. Clean, uniform cross section; water 2½ feet below surface, flowing on hardpan; used 2 years.
......	......	2.60	.71	Medium clay loam, underlain with hardpan and gravel beneath.	.....do..............	Measured June 17, 1912, 3 miles southwest of Hollister. Uniform cross section and grade; canal carrying small part of capacity; water flowing on hardpan; used 1 year.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Salmon River project, lateral A, Salmon River.	1	3.138	92.2	1.96	23.3	24.50	1.98	......	3.44	3.70
Salmon River project, coulee in main canal, Salmon River.	1	3.809	192.4	1.72	67.5	68.25	1.65	......	2.30	1.20
Salmon River project, main canal, Salmon River.	1	4.189	206.9	1.84	68.1	68.75	1.62	......	8.41	4.10
Salmon River project, check basin, Salmon River.	1	....	343.9	.....	......	......	......	......	34.2	......
Murphy Land & Irrigation Co. farm lateral.	1	.469	.685	.25	1.8	2.30	1.49	......	.030	4.40
Do	1	1.623	1.282	.28	4.3	4.58	1.03	......	.086	6.70
Do	1	5.254	1.454	.34	3.6	3.96	1.94	......	.562	38.60
Murphy Land & Irrigation Co., main canal.	1	4.568	19.3	.97	10.3	11.25	1.83	......	1.81	9.40
Do	1	3.812	21.7	.98	11.2	11.73	1.87	......	2.25	10.40
Farmers' Union, A-B, Boise River	3	1.69	111.1 96.6 124.4	.....	......	......	......	......	......	......
Do	1	2.44	99.7	.....	......	......	......	......	......	......
Farmers' Union, B-C, Boise River	2	3.30	98.0 125.3	.....	......	......	......	......	......	......
Farmers' Union, C-D, Boise River	1	4.40	114.1	.....	......	......	......	......	......	......
Settlers, A-B, Boise River	2	1.43	156.5 165.5	.....	......	......	......	......	......	......
Settlers, B-C, Boise River	1	1.73	163.4	.....	......	......	......	......	......	......
Settlers, C-D, Boise River	1	.95	158.6	.....	......	......	......	......	......	......
Settlers, B-D, Boise River	1	2.68	154.1	.....	......	......	......	......	......	......
Caldwell high line, A-B, Boise River.	2	2.25	116.0 96.3	.....	......	......	......	......	......	......
Caldwell high line, B-C, Boise River.	2	1.02	113.4 102.0	.....	......	......	......	......	......	......

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[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.20	0.73	Medium clay loam, underlain with limestone shale at 1½ feet.	Report D. H. Bark, 9th Biennial Report State Eng. Idaho, 1911-12.	Measured June 15, 1912. Uniform grade and clean cross section; canal carrying only part of capacity; water flowing on limestone shale; used 2 years.
......	......	.30	.15	Rock and clay loam..	.....do...............	Measured June 16, 1912. Coulee or natural water course; well silted greater part of section.
......	......	1.00	.48	Clay loam underlain by hardpan; rock exposed in places.	.....do...............	Measured June 16, 1912, below check basin. Clean, uniform cross section and grade; used 2 years.
......	......	......	1.09	Lava rock covered with clay loam 1 to 3 feet deep.	.....do...............	Measured June 14, 1912. Small lake about 62 acres; rather regular in outline; 1,200 feet of rock cut at outlet; used 2 years.
......	......	9.30	.45	Impervious clay loam.	.....do...............	Measured May 27, 1912. About 10 wooden drops in this ditch; regular cross section; irregular grade; used 2 years.
......	......	4.10	.19	.....do...............	.....do...............	Measured May 27, 1912. Ditch carrying only one-fifth capacity; uniform cross section; no weeds in channel; used 2 years.
......	......	7.30	.442	Varies between impervious clay loam and sandy loam, all underlain with hardpan.	.....do...............	Measured May 26, 1912. Irregular cross section; carrying only small part of capacity; numerous drops; varying grades; used 2 years.
......	......	2.10	.576	Clay loam mixed with gravel.	.....do...............	Measured May 23, 1912. Clean, uniform cross section; mostly side-hill section; well silted; used 3 years.
......	......	2.70	.82	Clay loam...........	.....do...............	Measured May 23, 1912. Clean, uniform cross section; well silted bottom and banks; used 3 years.
......	......	[1].78	[1].57	Clay, silt, and granite wash.	Report F. W. Hanna, in report of Boise Conference of Operating Engineers, U.S.R.S., Boise, Idaho, Nov., 1911.	Bottom.
......	......	[1]1.35	[1].82			
......	......	[1].49	[1].38			
......	......	[1]1.66	[1]1.12	.....do...............	.....do...............	Do.
......	......	[1].27	[1].20	Granite, sand wash, and lake deposit.	.....do...............	Side hill.
......	......	2.09	1.79			
......	......	1.85	1.26	Granite, sand wash, lake deposit, and volcanic ash.	.....do...............	Bench and bottom fill.
......	......	1.18	1.07	Sand and gravel, partly cemented.	.....do...............	Side hill.
......	......	1.29	1.16			
......	......	1.80	1.87	Cemented gravel and sand.	.....do...............	Do.
......	......	2.85	3.12	.....do...............	.....do...............	Bench.
......	......	.42	.44	.....do...............	.....do...............	Side hill and bench.
......	......	1.01	.67	Sand and gravel more or less cemented.	.....do...............	Side hill.
......	......	.95	.58			
......	......	.61	.43	Volcanic ash, clay and cemented gravel.	.....do...............	Bench.
......	......	2.77	1.85			

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Idaho—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Middleton Water Co., A–B, Boise River.	3	1.73 1.99 1.95	101.3 58.4 57.1							
Middleton Water Co. and Middleton Mill Co., Boise River.	1	14.91	107.6							
Do	1	16.15	96.0							
North Mora, A–B, Boise River	1	2.08	9.51							
North Mora, C–D, Boise River	4	2.04	4.43							
Rawson, A–B, Boise River	1	4.56	38.7							
Kuna, A–B, Boise River	1	1.56	29.1							
Teed, A–B, Boise River	1	2.00	11.2							
Eight-Mile, A–B, Boise River	1	5.69	32.2							
Kennedy, A–B, Boise River	1	5.81	20.4							
Eureka, A–B, Boise River	1	2.26	24.5							
Do	1	2.20	15.3							
Eureka (rating flume to C), Boise River.	1	3.96	11.3							
Do	1		5.06							
Ballantine, C–D, Snake River	1	.85	7.47							
Boise Valley, A–B, Snake River	3	1.80	35.4 18.6 14.6							
Ridenbaugh farm lateral, Snake River.	1	.682	.277	0.21	1.5	1.69	0.74		0.083	30.00
Do	1	.379	.364	.28	1.5	1.78	.78		.081	22.20
Do	1	1.534	1.219	.40	2.5	2.90	1.16		.096	7.90
Portneuf-Marsh Valley, Main Canal, Portneuf River.	1	1.881	43.6	1.44	19.8	20.75	1.50		1.35	3.10
Do	1	1.746	45.5	1.58	19.7	20.75	1.43		1.90	4.20
Do	1	3.000	50.3	1.71	19.5	20.58	1.44		4.80	9.50
Do	1	4.533	59.0	1.83	21.7	22.68	1.37		8.70	14.70
Do	1	4.862	73.0	2.12	24.8	25.90	1.25		14.00	19.20

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[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.25	0.83	Clay and silt overlain with wind-blown ash.	Report F. W. Hanna, in report of Boise Conference of Operating Engineers, U.S.R.S., Boise, Idaho, Nov., 1911.	Bottom.
......	......	5.13	2.04			
......	......	3.66	1.42			
......	......	[1]2.00	[1]1.31	Gravel, silt, and clay overlain with wind-blown ash.	do	Do.
......	......	[1]2.09	[1]1.25	do	do	Do.
......	......	2.52	.23	Hardpan overlain with mud.	do	Bench.
......	......	11.61	.86	do	do	Average; weeds in canal; bench.
......	......	2.29	.52	Mostly mud bottom underlain with hardpan.	do	Bench.
......	......	.60	.17	Hardpan overlain with mud.	do	Do.
......	......	11.96	1.39	do	do	Do.
......	......	2.32	1.18	do	do	Do.
......	......	1.82	.68	do	do	Do.
......	......	[1]8.36	[1]2.52	Clay, silt, muck, and sand.	do	Bottom.
......	......	[1]12.40	[1]2.20	do	do	Do.
......	......	[1]8.50	[1]1.46	do	do	Do.
......	......	[1]20.00	[1]1.84	do	do	Do.
......	......	[1]15.20	[1]1.96	Granite, sand wash, and silt.	do	Do.
......	......	[1]2.06	[1].93	Sand, granite wash, gravel, and silt.	do	Do.
......	......	[1]7.70	[1]1.88			
......	......	[1]5.52	[1]1.13			
......	......	43.90	1.17	Clay loam mixed with gravel.	Report D. H. Bark, 9th Biennial Report State Engineer, Idaho, 1911–12.	Measured June 27, 1912, 1 mile south of Meridian. Regular cross-section; weeds on bank; first half-section in low dike; used 8 years.
......	......	58.80	1.97	Deep and porous medium clay loam.	do	Measured June 26, 1912, 3 miles west of Meridian. Deep uniform cross-section; some weed growth in channel; used 5 years.
......	......	5.10	.35	Impervious clay loam.	do	Measured June 28, 1912, 2 miles west of Meridian. Uniform cross-section; parallels a larger lateral 10 feet away; used 5 years.
......	......	1.60	.57	Deep, uniform, and finely divided clay loam.	do	Measured Aug. 31, 1912, stations 981+72 to 1081+6. Carrying only small part of capacity; clean uniform grade and cross-section; used 1 year.
......	......	2.40	.86	do	do	Measured Aug. 31, 1912, stations 889+49 to 981+72. Balance same as foregoing.
......	......	3.20	1.28	do	do	Measured Aug. 31, 1912, stations 731+19 to 889+49. Balance same as foregoing.
......	......	3.30	1.39	do	do	Measured Aug. 31, 1912, stations 491+84 to 731+19. Balance same as foregoing.
......	......	3.90	1.82	do	do	Measured Aug. 21, 1912, stations 235+11 to 491+84. Balance same as foregoing.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
		Miles.	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Idaho—Continued.										
Portneuf-Marsh Valley, Lateral C, Portneuf River.	1	.478	24.1	1.37	12.2	13.20	1.41	......	1.11	4.60
Portneuf-Marsh Valley, lateral, Portneuf River.	1	1.309	13.17	.97	9.5	10.10	1.36	......	.94	7.10
Do	1	1.175	3.84	.68	5.4	5.95	1.02	......	.175	4.60
Louisiana.										
Ferre, pump	2	3.08	80.5 78.1	3.32 3.34	....	....	1.31 1.26	....	2.00 1.90	2.48 2.43
Montana.										
Big Ditch, Yellowstone River	1	22.00	254.5	......	......	......	......	......	65.1	25.60
Do	1	33.90	310.8	......	......	......	......	......	47.1	15.16
Do	1	30.40	300.7	......	......	......	......	......	29.1	9.68
Do	1	28.86	382.9	......	......	......	......	......	12.2	3.19
High line, Yellowstone River	1	18.51	75.2	......	......	......	......	......	20.3	27.05
Yellowstone, Yellowstone River	1	7.00	35.6	......	......	......	......	......	6.9	19.35
Italian, Yellowstone River	1	9.62	50.6	......	......	......	......	......	[1] 2.70	[1] 5.33
Canyon Creek, Yellowstone River	1	12.00	59.7	......	......	......	......	......	10.8	18.02
Mill, Yellowstone River	1	8.00	29.33	......	......	......	......	......	1.78	6.07
Flaherty flat, Yellowstone River	1	3.00	21.28	......	......	......	......	......	1.17	5.50
Merrill, Yellowstone River	1	8.25	30.81	......	......	......	......	......	5.26	17.07
West Gallatin Irrigation Co., West Gallatin River.	1	38.75	114.5	......	......	......	......	......	39.1	34.10
Do	1	26.50	93.7	......	......	......	......	......	26.3	28.10
Do	1	23.25	70.1	......	......	......	......	......	18.8	26.80

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[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	9.60	2.88	Very gravelly........	Report D. H. Bark, 9th Biennial Report State Engineer, Idaho, 1911–12.	Measured Sept. 3, 1912, 2 miles north of Downey. Clean uniform cross-section; water level in ditch about same as ground surface; used 1 year.
......	......	5.40	1.16	Clay loam slightly mixed with gravel.	.....do...............	Measured Sept. 3, 1912, 2 miles north of Downey. Clean uniform cross-section; carrying less than one-fourth capacity; uniform grade; used 1 year.
......	......	3.90	.41	Sandy loam mixed with small amount of gravel.	.....do...............	Measured Sept. 3, 1912, 2 miles north of Downey. Uniform cross-section; carrying very small part of full capacity; used 1 year.
......	......	.81	....	Acadia silt loam and heavy yellow clay.	Report W. B. Gregory, Journal Assn. Eng. Societies, vol. 49, No. 1, July, 1912.	Measured Aug. 7, 1911, from Benoit flume to Lyons Point flume.
......	......	.79				
......	......	1.16	....	6 miles sandy loam; 5 miles heavy clay; remainder light sandy loam.	Report Samuel Fortier, O. E. S. Bul. 172, 1906.	Measured Aug. 9–13, 1900 from Tilden's ranch to Hesper farm.
......	......	.45	....	....	.....do...............	Measured June 10–13, 1902 Received some inflow from High Line Canal and irrigated lands.
......	......	.32	....	....	.....do...............	Measured Aug. 4–6, 1902. Received some inflow from High Line Canal.
......	......	.11	....	....	.....do...............	Measured 1903. Received some inflow from both the High Line and the Yellowstone canals, and irrigated lands.
......	......	1.46	....	....	.....do...............	Measured 1903.
......	......	2.77	....	....	.....do...............	Do.
......	......	[1] 5.52	....	....	.....do...............	Measured 1903. Receives heavy inflow from canals and irrigated lands above it.
......	......	1.50	....	....	.....do...............	Do.
......	......	.76	....	....	.....do...............	Measured 1903. A large increase in this section in third and fourth miles from head due wholly to seepage.
......	......	1.83	....	....	.....do...............	Measured 1903.
......	......	2.07	....	....	.....do...............	Do.
......	......	.88	....	....	.....do...............	Measured July 18–20, 1900. No canals or irrigated lands to affect this section by waste water.
......	......	1.06	....	....	.....do...............	Measured June 24–25, 1902. No canals or irrigated lands to affect this section by waste water.
......	......	1.15	....	....	.....do...............	Measured 1903. No canals or irrigated lands to affect this section by waste water.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
		Miles	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Montana—Continued.										
Cameron or Kughen, West Gallatin River.	1	7.82	26.5	......	......	......	......	......	7.6	28.70
Kleinschmidt, West Gallatin River.	1	17.50	96.1	......	......	......	......	......	10.24	10.70
Middle Creek, West Gallatin River.	1	4.0	63.0	......	8.5	10.1	......	31.2	12.2	19.40
Republican, Bitter Root River......	1	3.6	120.5	......	11.25	15.12	......	9.31	34.3	28.50
Oregon.										
Adams (old), Little Klamath Lake.	1	6	16.99	......	......	......	......	1.37	1.73	10.20
Adams (new), Little Klamath Lake	1	8	18.16	......	......	......	......	......	2.28	12.60
Ankeny, Klamath Lake............	1	6.5	43.41	......	......	......	......	......	7.84	18.10
Pilot Butte, Deschutes River.......	1	2.07	88.8	......	......	......	......	1.0	9.4	10.60
Do............................	1	1.84	78.4	......	......	......	......	8.0	6.6	8.42
Do............................	1	3.0	37.8	......	24	......	......	2.2	5.2	13.80
Do............................	1	1.78	30.4	......	32	......	......	0.0	1.6	5.26
Do............................	1	5.81	28.8	......	36	......	......	0.0	2.5	8.68
Do............................	1	2.25	26.4	......	19	......	......	7.9	4.1	15.50
Oregon Central, Deschutes River...	1	2.51	56.6	......	36.3	......	......	0.0	17.7	31.30
Do............................	1	2.18	38.9	......	......	......	......	0.0	15.9	40.90
Maxwell, Umatilla River...........	1	1.75	16.3	......	......	......	......	0.0	3.2	19.60

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
		3.67			Report Samuel Fortier, O. E. S. Bul. 172, 1906.	Measured 1903. Some inflow seepage.
		.61			do	Measured 1903. Seepage inflow from creek channels and narrow irrigated valleys.
		4.85			Report Samuel Fortier, O. E. S. Bul. 104, Sep. No. 4, 1900.	Measured June 27, 1900.
		7.92		Gravelly	do	Measured July 21–23, 1900, from headgate to north line of Grantsdale.
		1.7			Report F. L. Kent, O. E. S. Bul. 158, Sep. No. 4, 1904.	Measured July 15, 1904, upper end of section 600 feet below Lost River flume. Grade, 1.8 feet per mile.
		1.57			do	Measured July 16, 1904, upper end of section, 300 feet below Lost River flume. Grade, 0.7 foot per mile.
		2.78		First mile along a very rocky and in places steep hillside.	do	Measured Aug. 20, 1904, upper end of section, 200 feet below power plant. Doubtless heavy loss in first mile.
		5.12		Extremely rough	Report A. P. Stover, O. E. S. Cir. 67.	Measured Sept. 5, 1905. Heavy grade, numerous natural drops. Stations 75+100 to 184+50.
		4.57		do	do	Measured Sept. 5, 1905. Heavy grade, numerous natural drops. Stations 184+50 to 281+40.
		4.59		Rough in places, natural channels in places, some silting where grade is light.	do	Measured Sept. 8, 1905, stations 71+00 to 228+90.
		2.96			do	Measured Sept. 8, 1905, from stations 228+90 to 322+90.
		1.49		Rock cut	do	Measured Sept. 8, 1905, from stations 322+90 to 630+00. Heavy grade first one-third section; remainder light grade.
		6.90			do	Measured Sept. 8, 1905, from stations 630+00 to 760+00. Channel entirely in cut; grade light.
		12.5		Rock cut first 2 miles; remainder in earth, with small rock cuts at intervals.	do	Measured Sept. 6, 1905, from station 34+75 to 170+50. Bottom well silted; new channel; dry for some time; porous.
		18.7		Earth, with small rock cuts at intervals.	do	Measured Sept. 6, 1905, from station 170+50 to 285+50. New channel in good condition; dry for some time; lower end of section well silted.
		11.2		Mostly cement gravel and bowlders.	do	Measured July 20, 1905, headgate to waste gate No. 2. New channel; only slightly silted; grade uniform.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Oregon—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Maxwell, Umatilla River	1	0.23	13.1	.....	.....	.....	.....	0.0	1.6	12.20
Do	1	1.75	11.5	.....	.....	.....	.....	0.0	5.6	48.70
Do	1	1.50	5.5	.....	.....	.....	.....	0.0	2.4	43.70
Irrigon, Umatilla River	4	8.33	21.6	.....	.....	.....	.....	0.0	15.9	73.60
Do	1	.947	15.6	.....	.....	.....	.....	0.0	3.0	19.20
Do	1	.947	12.6	.....	.....	.....	.....	0.0	1.3	10.30
Do	1	1.022	11.3	.....	.....	.....	.....	.8	2.0	17.70
Do	1	1.042	8.5	.....	.....	.....	.....	0.0	.4	4.70
Do	1	.815	8.1	.....	.....	.....	.....	0.0	.3	3.70
Do	1	1.193	7.8	.....	.....	.....	.....	0.0	2.0	25.60
Do	1	.530	7.1	.....	.....	.....	.....	0.0	.9	12.70
Do	1	.890	6.2	.....	.....	.....	.....	0.0	1.0	16.10
Do	1	.947	5.2	.....	.....	.....	.....	0.0	1.0	19.20
Do	1	.379	4.2	.....	.....	.....	.....	0.0	1.7	40.50
Do	1	8.901	17.7	.....	.....	.....	.....	1.1	6.3	35.60
Bowne, Lost River	1	1	9.9	.....	.....	.....	.....	.....	1.0	10.10
Dunn (lateral), near Ashland	1	2.25	2.21	.....	.....	.....	.....	.....	.32	14.50

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
		53		Cement gravel cut	Report A. P. Stover, O. E. S. Cir. 67.	Measured July 20, 1905, waste gate No. 2 to end of gravel cut.
		27.8		Coarse, sandy soil, in some few places well silted.	do	Measured July 20, 1905, from end of gravel cut to lateral No. 1. Under comparatively low velocities scouring causes loss through porous lining.
		29.1		Much the same as preceding section.	do	Measured July 20, 1905, from lateral No. 1 to siphon intake. Toward lower end section quite well silted.
		8.84			do	Measured July 13, 1905, from headgate to station 440. See detailed description in succeeding 10 sections measured.
		20.3		1,800 feet flume, 4.8 feet wide, 2 feet deep; remainder coarse, porous gravel and shifting sand.	do	Measured Aug. 8, 1905, from headgate to station 50. Loss mostly through portion in coarse, porous gravel; no deposition of silt; cross section irregular; banks of shifting sand.
		10.9		Heavy sand and gravel cuts.	do	Measured Aug. 8, 1905, from station 50 to station 100. Irregular cross section; no silting.
		17.3		Much gravel and loose sand.	do	Measured Aug. 8, 1905, from station 100 to station 154. Uniform cross section; steep side hill; silting only at intervals.
		4.5		Fine sand and gravel.	do	Measured Aug. 8, 1905, from station 154 to station 209. Uniform cross section; well silted.
		4.5		Porous gravel, with bottom filled 8 to 10 inches deep with fine sand.	do	Measured Aug. 8, 1905, from station 209 to station 252. Uniform cross section; quite well silted.
		21.5		Sand, with hardpan at depths of 4 to 8 feet.	do	Measured Aug. 8, 1905, from station 252 to station 325. Uniform cross section; part of section well silted.
		23.9		Exposed gravel in lower end of section.	do	Measured Aug. 9, 1905, from station 325 to station 353. Uniform cross section; bottom well silted.
		18.1		Through sand cuts	do	Measured Aug. 9, 1905, from station 353 to station 400. Uniform cross section; fairly well silted.
		20.6		Much the same as preceding section.	do	Measured Aug. 9, 1905, from station 400 to station 450. The several hundred feet on ridge seeps heavily.
				Mostly well silted coarse sand.	do	Measured Aug. 9, 1905, from station 450 to station 470.
		4.0			do	Measured Sept. 19, 1905. See detailed description in preceding 10 sections measured.
		10.1			Report F. L. Kent in office manuscript.	Measured 1905. Supplied from pumping plant.
		6.4			do	Measured 1905.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Utah.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Logan and Richmond, Logan River	2	0.549	77.70	......	14.25	19.05	......	......	1.14	1.47
Do	2	.71	71.44	......	14.65	19.18	......	......	2.26	3.16
Do	2	.515	70.71	......	14.05	18.10	......	......	1.89	2.67
Do	2	.306	72.32	......	15.15	19.30	......	......	.34	.47
Do	1	.843	58.69	......	12.30	16.80	......	......	2.72	4.63
Do	6	1.449	64.41– 91.59	......	13.20	18.40	......	......	7.40	9.09
Logan, Hyde Park and Smithfield, Logan River.	6	0.244– .947	36.66– 52.78	......	......	......	......	......	......	......
Do	7	1.36	37.43– 58.57	......	14.20	17.10	......	......	4.89	9.82
Do	1	1.32	48.0	......	......	......	......	......	21.30	44.40
East Jordan, Jordan River	1	2.5	42.46	......	......	......	......	......	6.46	15.30
Bear River main line, Bear River	1	1.5	279.3	......	......	......	......	1.75	14.03	5.02
Do	1	.75	263.6	......	......	......	......	......	5.20	1.97
Do	1	3.25	258.4	......	......	......	......	.75	2.89	1.12
Do	5	5.5	356.3	......	......	......	......	......	35.79	10.04
			458.6	......	......	......	......	......	70.3	15.30
			424.2	......	......	......	......	......	70.7	16.70
			380.4	......	......	......	......	......	59.4	15.60
			298.9	......	......	......	......	......	33.3	11.10
Bear River west line, Bear River	1	3.5	138.6	......	......	......	......	2.93	[1] 1.88	[1] 1.36
Do	1	4.0	137.5	......	......	......	......	6.29	1.84	1.34
Do	1	2.5	129.4	......	......	......	......	17.3	2.14	1.65
Do	1	6.5	110.0	......	......	......	......	62.3	4.47	4.06

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
		2.67			Report George L. Swendsen, O. E. S. Bul. 104, Sep. No. 3, 1900.	Measured 1899. Averages only.
		4.45			do	Do.
		5.20			do	Do.
		1.50			do	Do.
		5.50			do	Do.
		6.27			do	Measured 1900. Average measurements for identical sections.
		3.85			do	Measured 1899. Loss in per cent average for six measurements.
		7.22			do	Measured 1900. Average measurements for identical sections. Measurement July 12 omitted. Steep mountain side.
		33.60			Report Samuel Fortier, Utah Expt. Sta. Bul. 26, 1893.	Measured Aug. 31, 1893. Upper end of section at headgate. All in canyon.
		6.10		Coarse	Report Irrigation Investigations for 1900, O. E. S. Bul. 104.	Measured Aug. 11, 1900, along steep hillside from headgate to power plant.
		3.30		Mostly rock cut, some disintegrated limestone.	Report A. P. Stover, O. E. S. Bul. 119, 1901.	Measured June 25, 1901, from headgate to flume No. 1.
		2.60		Porous side hill along river bottom.	do	Measured June 25, 1901, from flume No. 1 to flume No. 3.
		.34		Heavy compact soapstone formation.	do	Measured June 25, 1901, from flume No. 3 to Corrinne division gates. Along side hill bluffs.
		1.83		See measurements for 1901.	Report J. C. Wheelon, of Utah Sugar Co., office manuscript.	Measured May 28, 1902, from headgate to Corrinne division gates.
		2.79		do	do	Measured June 28, 1902, from headgate to Corrinne division gates.
		3.03		do	do	Measured July 28, 1902, from headgate to Corrinne division gates.
		2.84		do	do	Measured Aug. 26, 1902, from headgate to Corrinne division gates.
		2.03		do	do	Measured Sept. 22, 1902, from headgate to Corrinne division gates.
		1.39			Report A. P. Stover, O. E. S. Bul. 119, 1901.	Measured June 25, 1901, from Corrinne division gates to Malade flume. Entirely in excavation.
		.34			do	Measured June 25, 1901, from Malade flume to bridge No. 13. Entirely in excavation, uniform conditions.
		.66			do	Measured June 25, 1901, from bridge No. 13 to bridge No. 18. Entirely in excavation; uniform conditions.
		.63			do	Measured June 26, 1901, from bridge No. 18 to Roweville.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Utah—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec.-feet.*	*Sec.-feet.*	*Per cent.*
Bear River, west line, Bear River	6	16.5	199.7	......	......	......	......	......	20.2	10.10
			245.4	......	......	......	......	......	20.0	8.15
			218.0	......	......	......	......	......	19.6	9.00
			185.5	......	......	......	......	......	12.6	6.80
			151.7	......	......	......	......	......	19.3	12.70
			81.6	......	......	......	......	......	6.7	8.20
Bear River, Corrinne line, Bear River.	1	8.5	118.9	......	......	......	......	31.9	7.37	6.20
Do	1	5.5	79.7	......	......	......	......	28.3	4.53	5.68
Do	1	3.75	55.5	......	......	......	......	12.13	2.69	4.85
Anderson & Spilsbury, near Toquerville.	1	.75	1.76	......	......	......	......	......	.41	23.30
Peter Anderson, near Bellevue	1	7.0	2.93	......	......	......	......	......	.35	12.00
Bellevue Town, Bellevue	1	1.5	8.98	......	......	......	......	......	.58	6.50
Cottonwood, St. George	1	14.0	7.03	......	......	......	......	......	3.17	45.10
Brigham Dalton, Rockville	1	.5	.72	......	......	......	......	......	.04	5.60
Davis and Pace, near New Harmony	1	.12	2.29	......	......	......	......	......	.18	7.90
Dry field, near New Harmony	1	1.0	2.32	......	......	......	......	......	.28	12.10
Flanigan, near Springdale	1	.75	14.5	......	......	......	......	......	.86	5.90
Hurricane, near Hurricane	1	4.12	21.84	......	......	......	......	......	2.25	10.30
William Jackson, near Toquerville	1	.75	1.2	......	......	......	......	......	.02	1.70
La Verkin, near Toquerville	2	.75	13.55	......	......	......	......	......	.45	3.30
			7.34	......	......	......	......	......	.01	.10
La Verkin field, near Toquerville	1	.5	3.45	......	......	......	......	......	.56	16.20
Leeds, near Leeds	1	1.0	9.60	......	......	......	......	......	.65	6.80
Daniel Mathews, near Mount Dell	1	.25	1.51	......	......	......	......	......	.17	11.20
Mill Race, Virgin	1	.095	.74	......	......	......	......	......	.08	10.80
Mount Carmel City, near Mount Carmel.	1	.75	4.45	......	......	......	......	......	.02	.50

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	0.61	....	....	Report J. C. Wheelon, of Utah Sugar Co., office manuscript.	Measured May 28, 1902, from Corrinne division gates to Roweville.
......	......	.49	....	....	do	Measured June 28, 1902, from Corrinne division gates to Roweville.
......	......	.54	....	....	do	Measured July 28, 1902, from Corrinne division gates to Roweville.
......	......	.41	....	....	do	Measured Aug. 26, 1902, from Corrinne division gates to Roweville.
......	......	.77	....	....	do	Measured Sept. 22, 1902, from Corrinne division gates to Roweville.
......	......	.50	....	....	do	Measured Oct. 24, 1902, from Corrinne division gates to Roweville.
......	......	.73	....	....	Report A. P. Stover, O. E. S. Bul. 119, 1901.	Measured June 26, 1901, from Corrinne division gates to bridge No. 14.
......	......	1.03	....	....	do	Measured June 26, 1901, from bridge No. 14 to Red Flume.
......	......	1.29	....	....	do	Measured June 27, 1901, from Red Flume to bridge No. 25.
......	......	31.00	....	¾ sandy loam; ¼ river worn gravel and bowlders 2 inches to 2 feet in diameter.	Records of office State engineer of Utah.	Approximate grade 5 feet per mile.
......	......	1.70	....	5 miles solid rock in ravine; 2 miles black loam.	do	700 feet fall.
......	......	4.30	....	⅓ bowlders; ⅔ volcanic soil.	do	40 feet fall.
......	......	3.20	....	½ solid sandstone ravines; ⅓ sand and ⅙ black loam.	do	700 feet fall.
......	......	11.10	....	Sandy loam	do	4 feet fall.
......	......	66.00	....	Fine gravel and clay	do	1½ feet fall.
......	......	12.10	....	Sand and clay	do	7 feet fall.
......	......	7.90	....	Black loam and gravel.	do	5 feet fall.
......	......	2.50	....	Volcanic ledge; gypsum in places.	do	20 feet fall.
......	......	2.20	....	Sandy loam	do	5 feet fall.
......	......	4.40	....	Volcanic ledge; gypsum in places.	do	5 feet fall. Measured May 10, 1910.
......	......	.18	....	do	do	5 feet fall. Measured May 26, 1910. Coated with clay since previous measurement.
......	......	32.40	....	Sandy loam	do	5 feet fall.
......	......	6.80	....	Bedded sandstone with strata dipping toward the mountain.	do	50 feet fall.
......	......	45.00	....	Sandy loam and gravel.	do	2 feet fall.
				Sandy loam	do	1 foot fall.
......	......	.60	....	Channel coated with clay deposit from floods.	do	6 feet fall.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
Utah—Continued.		*Miles.*	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec. feet.*	*Sec. feet.*	*Per cent.*
North Ash Creek, near Bellevue	1	0.50	1.66	......	......	......	......	......	0.17	10.20
Orderville Town, near Orderville	1	.25	4.45	......	......	......	......	......	[1].01	.22
Pace & Prince, near New Harmony	1	.123	1.85	......	......	......	......	......	.23	12.40
Henry A. Pace No. 1, near New Harmony.	1	.21	.58	......	......	......	......	......	.08	13.80
Rockville South Field, near Rockville	1	.19	3.7	......	......	......	......	......	.11	3.00
Joseph Sanders, near Mount Dell	1	.25	1.01	......	......	......	......	......	.05	5.00
Santa Clara South Field, near Santa Clara.	1	.40	4.57	......	......	......	......	......	.73	16.00
Santa Clara Town, near Santa Clara.	1	.25	2.61	......	......	......	......	......	.03	1.20
Gottlieb Schmutz No. 1, near New Harmony.	1	.25	.41	......	......	......	......	......	.01	2.40
Shones Creek, near Shonesburg	1	.50	1.11	......	......	......	......	......	.43	38.70
Spring Ditch, near Toquerville	1	.25	2.52	......	......	......	......	......	.71	28.20
St. George and Washington Field, near Washington.	1	4.25	51.98	......	......	......	......	......	1.58	3.00
West Field, Toquerville	1	.17	3.84	......	......	......	......	......	.06	1.60
Huntington, Huntington	1	1.25	17.72	......	......	......	......	......	1.39	7.80
Washington.										
Prosser Falls Irrigation Co., Lateral, Yakima River.	1	.379	.50	......	......	......	......	......	.32	64.00
Kennewick, Yakima River	4	9.0	123.0	......	......	......	......	......	32.0	26.00
			161.0	......	......	......	......	......	30.0	18.60
			148.0	......	......	......	......	......	24.0	16.20
			78.6	......	......	......	......	......	9.8	12.50
Do	2	2.6	131.0	......	......	......	......	......	5.0	3.80
			124.0	......	......	......	......	......	4.0	3.20
Do	2	8.6	68.8	......	......	......	......	......	10.9	15.80
			91.0	......	......	......	......	......	23.0	25.30
Do	1	6.0	120.0	......	......	......	......	......	13.0	10.80
Selah-Moxee, Yakima River	2	1.42	53.3	......	......	......	......	......	1.8	3.40
			49.8	......	......	......	......	......	1.2	2.40
Do	1	2.6	49.8	......	......	......	......	......	2.1	4.20
Do	1	1.57	29.0	......	......	......	......	......	.2	.70
Sunnyside main line, Yakima River	....	30.0	636.0	......	......	......	......	258.0	38.0	6.00
Do	....	18.0	340.0	......	......	......	......	171.0	40.0	11.80

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[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
		20.00		Sandy loam	Records of office State engineer of of Utah.	5 feet fall.
		1.90		Channel coated with thick layer of clay.	do	2 feet fall, ground saturated from recent rains.
				Gravel and black loam.	do	1 foot fall.
		66.00		do	do	2 feet fall.
		15.70		Sandy loam	do	2 feet fall.
		19.80		do	do	3 feet fall.
		40.00		do	do	4 feet fall.
		4.60		do	do	2 feet fall, flowing a much larger stream a few hours before.
		9.80		Gravel and black loam.	do	2 feet fall.
		77.40		Sand and gravel	do	7 feet fall.
				¾ sandy loam; ¼ river worn gravel and bowlders, 2 inches to 2 feet in diameter	do	2 feet fall.
		.70		Sandy loam	do	21 feet fall.
		9.20		River rocks and sandy loam.	do	3 feet fall.
		6.30		Clay and blue slate rock points.	do	7 feet fall.
				Mostly coarse gravel covered with soil 4 to 9 inches deep.	Report O. L. Waller, O. E. S. Bul. 104, 1900.	Measured Oct. 31, 1900.
		2.90			Report S. O. Jayne, O. E. S. Bul. 188.	Measured Sept. 9, 1904, De Moss's bridge to flume No.1
		2.10			do	Measured May 11, 1906, De Moss's bridge to flume No.1
		1.80			do	Measured Sept. 27, 1906, De Moss's bridge to flume No.1
		1.40			do	Measured Oct. 16, 1906, De Moss's bridge to flume No. 1
		1.50			do	Measured Sept. 27, 1906, flume No. 1 to flume No.2.
		1.20			do	Do.
		1.80			do	Measured Sept. 9, 1904, flume No. 1 to flume No. 3.
		2.90			do	Measured May 11, 1906, flume No. 1 to flume No. 3.
		1.80			do	Measured Oct. 16, 1906, flume No. 2 to flume No. 3.
		2.40			do	Measured July 3, 1906, flume to Butterfield's bridge.
		1.70			do	Measured Aug. 21, 1906, flume to Butterfield's bridge.
		1.60		Mostly seamy basaltic rock.	do	Measured Aug. 21, 1906, flume to northeast corner section 21.
		.40			do	Measured July 6, 1906, cemetery to Rankin hopyard.
		.20	.48		Report J. C. Stevens, Trans. Am. Soc. C. E., vol. 71, p. 339, 1909.	Mean of continuous measurement, Apr. 16 to Sept. 15-1909. From intake to 30-mile station.
		.65	1.04		do	Mean of continuous measurement, Apr. 16 to Sept. 15, 1909. From 30-mile station to 48-mile station.

TABLE I.—*Seepage*

Canal and stream or locality.	Number of measurements.	Section measured.		Dimensions of canal.			Velocity in canal.	Diversions in section.	Total loss in section.	
		Length.	Flow at upper end.	Mean depth.	Width of water surface.	Length of wetted perimeter.				
		Miles.	*Sec.-ft.*	*Ft.*	*Feet.*	*Feet.*	*Feet per sec.*	*Sec. feet.*	*Sec. feet.*	*Per cent.*
Washington—Continued.										
Sunnyside main line, Yakima River.	....	12.0	129.0	.....	......	......	......	99.0	21.0	16.30
Sunnyside, Snipes Mountain Lateral, Yakima River.	....	9.0	89.0	.....	......	......	......	57.0	12.0	13.50
Wyoming.										
Wheatland No. 2, Laramie River	2	1.50	89.7	.....	......	......	......	00.0	4.35	4.85
			36.5	.....	......	......	......	0.0	1.46	4.00
Do	2	2.50	85.3	.....	......	......	......	0.0	4.23	4.96
			35.1	.....	......	......	......	0.0	1.05	2.99
Do	2	2.40	81.1	.....	......	......	......	0.0	3.06	3.77
			34.0	.....	......	......	......	10.95	[1].27	[1].79
Do	2	4.40	78.0	.....	......	......	......	25.79	2.78	3.56
			23.3	.....	......	......	......	12.05	[1]2.03	[1].87
Do	2	1.70	49.4	.....	......	......	......	0.0	.20	.40
			13.3	.....	......	......	......	0.0	1.07	8.04
Do	2	2.17	49.2	.....	......	......	......	20.88	.48	.97
			12.2	.....	......	......	......	5.64	.19	1.56
Do	1	2.33	27.9	.....	......	......	......	12.31	.15	.54

[1] Gain.

measurements—Continued.

Loss per mile.			Loss per square foot of wetted area in 24 hours.	Character of material in the channel.	Source of information.	Remarks.
Maximum.	Minimum.	Mean.				
Per cent.	*Per cent.*	*Per cent.*	*Cu. feet.*			
......	......	1.36	1.65	....	Report J. C. Stevens, Trans. Am. Soc. C. E., vol. 71, p. 339, 1909.	Mean of continuous measurement, Apr. 16 to Sept. 15, 1909. From 48-mile station to 60-mile station.
......	......	1.50	1.24	....	......do...............	Mean of continuous measurement, Apr. 16 to Sept. 15, 1909.
......	......	3.23	....	....	Report Clarence T. Johnston, O. E. S. Bul. 104, 1900.	Measured July 9-11, 1900, from station 1 (headgate) to station 2.
......	......	2.67	....	....	......do...............	Measured Aug. 20-22, 1900, from station 1 (headgate) to station 2.
......	......	1.98	....	....	......do...............	Measured July 9-11,1900, from station 2 to station 3.
......	......	1.20	....	....	......do...............	Measured Aug. 20-22, 1900, from station 2 to station 3.
......	......	1.57	....	....	......do...............	Measured July 9-11, 1900, from station 3 to station 4.
......	......	1.33	....	....	......do...............	Measured Aug. 20-22, 1900, from station 3 to station 4.
......	......	.81	....	....	......do...............	Measured July 9-11, 1900, from station 4 to station 5.
......	......	1.20	....	....	......do...............	Measured Aug. 20-22, 1900, from station 4 to station 5.
......	......	.24	....	....	......do...............	Measured July 9-11, 1900, from station 5 to station 6.
......	......	4.73	....	....	......do...............	Measured Aug. 20-22, 1900, from station 5 to station 6.
......	......	.45	....	....	......do...............	Measured July 9-11, 1900, from station 6 to station 7.
......	......	.72	....	....	......do...............	Measured Aug. 20-22, 1900, from station 6 to station 7.
......	......	.23	....	....	......do...............	Measured July 9-11, 1900, from station 7 to station 8.

FACTORS AFFECTING SEEPAGE.

It is not within the scope of this publication to include a detailed discussion of the various factors influencing seepage, but in order to form a reliable estimate of the loss by seepage from a proposed canal, the principal factors should be carefully considered. Briefly these are:

(1) Size and shape of grains and general character of materials.

(2) The gradual deposition of silt.

(3) Depth of water over the wetted perimeter.

(4) The relation which the wetted perimeter of the canal bears to other hydraulic elements.

(5) Velocity of water in canal.

(6) Inflow of seepage water.

(7) Temperature of the soil and the water.

A study of the results of the measurements secured brings out the close relation existing between the unit loss as expressed in percentage of flow and the size of the canal. Three hundred and twenty-three separate and distinct sets of measurements are grouped in Table II according to the capacity of the channels. It is interesting to note in this table the fairly constant decrease in the average loss in per cent per mile as the capacity increases.

TABLE II.—*Summary of seepage measurements expressed in terms of per cent of total flow lost per mile of channel for various sized canals.*

Capacity of canal (second-feet).	Number of tests.	Average loss per mile.	Capacity of canal (second-feet).	Number of tests.	Average loss per mile.
		Per cent.			*Per cent.*
Less than 1	16	25.7	50 to 75	31	4.3
1 to 5	37	20.2	75 to 100	26	2.7
5 to 10	30	11.7	100 to 200	45	1.8
10 to 25	49	12.1	200 to 800	27	1.2
25 to 50	48	5.5	800 and over	14	1.0

THE CARRYING CAPACITIES OF CONCRETE-LINED CANALS.

The laws governing the flow of water in concrete-lined channels do not differ from those for any other waterway. The force of gravity which produces motion in the water of a canal on a given grade is usually quite evenly counterbalanced by the various conditions which retard flow. These retarding influences are: (1) The frictional resistance of the wetted perimeter of the channel; (2) the influence of air in motion; (3) the existence of sharp curves, projecting objects, and irregularities of cross section, alignment, and grade; (4) the presence of sand, gravel, stones, or other shifting material; and (5) the presence of aquatic vegetation in the water or any rough coating on the perimeter of the canal.

The study of hydraulics has not yet reached that stage which will justify the assignment of definite values to the various influences which retard flow and thereby lower the efficiency of irrigation canals. One can do little more than consider all such factors collectively and designate them by the common term "frictional resistance." This has been done in the empirical formula known as Kutter's, where the letter n, called the coefficient of friction, represents not only the degree of roughness of the channel but all the other retarding influences to which reference has been made.

All the data pertaining to the carrying capacities of concrete-lined canals procurable at this writing (March, 1914) have been assembled and summarized in Table III. These results have been derived from a number of sources and represent rather wide differences in channel conditions. They likewise represent the work of a number of engineers who have employed somewhat different methods in making the necessary measurements. They are therefore not strictly comparable, but may be used as a basis for general deductions.

TABLE III.—*Measurements of flow in concrete-lined canals giving hydraulic*

Canal and location.	Shape of section.	Bottom width.	Depth.	Discharge.	Mean hydraulic radius.	Slope of water surface.	Total fall.	Length tested.
Idaho.		*Feet.*	*Feet.*	*Sec.-ft.*			*Feet.*	*Feet.*
Ridenbaugh, Boise Valley	Trapezoidal slopes 1½ to 1.	10	4.24	294	2.75	0.000237	0.114	484
		10	4.28	294	2.76	.000262	.229	875
		10	4.35	294	2.81	.000170	.058	340
		10	4.30	294	2.81	.000237	.401	1,699
		10	4.58	318	2.96	.000245	.408	1,665
		10	4.15	257	2.69	.000242	.358	1,478
		10	......	50	1.30	....	......	1,000-2,400
		10	......	103	2.13	....	......	1,000-2,400
		10	......	230	2.73	....	......	1,000-2,400
		10	......	382	3.29	....	......	1,000-2,400
		10	......	50	1.30	....	......	1,000-2,400
		10	......	103	2.06	....	......	1,000-2,400
		10	......	230	2.72	....	......	1,000-2,400
		10	......	382	3.24	....	......	1,000-2,400
		10	......	376	3.11	....	......	1,000-2,400
		10	......	318	2.90	....	......	1,000-2,400
		10	......	59	1.37	....	......	1,000-2,400
King Hill, Snake River	Trapezoidal slopes 2 to 1.	16	2.17	92.5	1.71	.000187	0.121	650
		10	1.62	54.5	1.25	.000452	.167	369
		10	1.62	54.8	1.25	.000448	.248	556
		10	1.62	54.6	1.25	.000450	.415	925
Boise Main Canal, section No. 2, Boise Valley.	Trapezoidal slopes 1½ to 1.	40	......	316	2.14	.000300	.300	1,000
		40	......	1,027	3.88	.000388	.388	1,000
		40	......	476	2.64	.000362	.362	1,000
		40	......	245	1.95	.000288	.288	1,000
		40	......	119	1.44	.000288	.288	1,000
		40	......	1,209	4.22	.000312	.312	1,000
Boise Main Canal, section No. 3, Boise Valley.	do	40	......	1,011	4.33	.000263	.630	2,400
		40	......	470	2.45	.000334	.800	2,400
		40	......	470	2.65	.000246	.590	2,400
		40	......	238	1.87	.000300	.720	2,400
		40	......	238	2.09	.000204	.490	2,400
Boise Main Canal, section No. 4, Boise Valley.	do	40	......	1,027	3.64	.000316	.757	2,400
		40	......	456	2.89	.000147	.353	2,400
New York Canal, Payette-Boise.	Trapezoidal.	39.6	5.6	1,824	5.23	.0001611	0.097	602
Ridenbaugh, Boise	do	10	2.7	221	2.54	.000251	0.226	901
Do	do	10	3.2	316.7	2.91	.000283	......	1,020.6
Twin Falls North Side, near Milner.	Nearly rectangular.	40	......	2,637	5.434	.000639	2.132	1,900
Oregon.								
Umatilla, U. S. Reclamation Service project.	Trapezoidal slopes 1¼ to 1.	1.5	......	5.7	.58	.00070	.652	932
Do	Semicircular	[1]4.9	......	205	2.13	.00140	.9	640
		[1]4.9	......	205	2.17	.00167	.2	120
		[1]4.9	......	205	2.15	.00273	.6	220
		[1]4.9	......	205	2.12	.00177	1.9	1,075

[1] Radius.

elements, value of "C" in Chezy's formula and "n" in Kutter's formula.

Velocity feet per second.	C in Chezy formula.	n in Kutter's formula.	Method of measuring discharge.	Method of measuring slope.	Condition of surface, etc.	Remarks.	Reference and authority.
4.23	165.5	0.0106	Current meter.	Level and hook gage.	Lining consists of 3½ inches concrete base with ½ inch mortar coat. Depth 6.5 inches with 1 foot concrete berm on top. Maximum depth of water 6 feet. Surface equivalent to sidewalk finish.	Tangent; practically no gravel.	Unpublished records of Office Irrigation Investigations. Measurements by Don H. Bark.
4.18	155.2	.0114				Reverse curve; a few cobblestones.	
4.08	187.0	.0095				Tangent; a few cobblestones.	
4.15	161.5	.0110				Total of above 3...	
4.13	153.5	.0116				Same 2 months later, more gravel on bottom.	
3.82	149.6	.0118				Same 2 months later still.	
2.45	119	.0132	..do.....	Gages.....	Same as above. Surface very smooth.	Numerous curves.	Records of U. S. Reclamation Service. Measurements by W. G. Steward under the direction of F. W. Hanna.
2.32	130	.0130					
3.35	145	.0122					
3.99	147	.0124					
2.43	123	.0127					
2.45	129	.0131					
3.37	158	.0112					
4.08	141	.0118					
4.32	142	.0126					
4.15	138	.0129					
2.60	130	.0122					
2.06	115.2	.0140	..do.....	Level and hook gage	Lining 4 inches thick, hand tamped; no surface coat; rough finish; no moss.	Partly tangent....	Unpublished records of Office of Irrigation Investigations. Measurements by Don H. Bark.
2.54	107.3	.0144				Nearly all curves..	
2.55	108.1	.0143				One curve.........	
2.55	107.5	.0143				Combination of above two.	
3.08	121	.0140	..do.....	Level, and with gages chipped into concrete every 200 feet.	Rough troweled surface. First measurements had considerable rock and stone in bottom, others had only a small quantity.	All tangent, gaged 500 feet below inlet and 300 feet above outlet.	Records of U. S. Reclamation Service. Measurements by W. G. Steward under direction of F. W. Hanna.
4.68	121	.0154					
3.57	115	.0152					
2.64	111	.0149					
1.84	91	.0170					
4.91	135	.0139					
3.90	116	.0164	...do.....	...do.......	Much gravel in bottom.	Tangent...........	Same as above.
3.81	133	.0130	..do.....	...do.......	Very little gravel in bottom. Concrete rather rough and some of it disintegrated due to freezing during construction.	....do.............	Do.
3.48	136	.0129					
2.67	113	.0147					
2.35	114	.0148					
5.00	148	.0124	..do.....	...do.......	Similar to set above. Concrete troweled to smoother surface.	Number of sharp curves.	Do.
2.98	145	.0123					
5.48	188.7	.0101	Vertical curves.	Level and hook gage.	Medium rough concrete, plastered joints.	Tangent...........	F. C. Scobey, Irrigation Investigations.
3.65	144.8	.0121	...do.....	...do.......	Very smooth cement wash on concrete.	.....do............	Do.
4.14	......	.0124	...do.....	...do.......	.....do...........	One slight curve approximately same as above.	B. P. Fleming, Irrigation Investigations.
8.21	139	.0138	...do....	...do.......	Rough rock cut rather lightly concreted, leaving an irregular undulating surface.	Tangent...........	F. C. Scobey, Irrigation Investigations.
2.06	102	.013	Current meter.	Level and gages.	Surface smooth and regular.	Slight curve.......	Records of U. S. Reclamation Service.
7.10	129	.0132	..do.....	...do.......	Concrete built with forms not troweled. Grain of lumber shows.	Tangent...........	Do.
6.86	114	.0149				All on curve with 100-foot radius.	
6.94	90	.0189				All on curve with 50-foot radius.	
7.15	119	.0142				Slight curve.......	

TABLE III.—*Measurements of flow in concrete-lined canals giving hydraulic*

Canal and location.	Shape of section.	Bottom width.	Depth.	Discharge.	Mean hydraulic radius.	Slope of water surface.	Total fall.	Length tested.
Oregon—Continued.		*Feet.*	*Feet.*	*Sec.-ft.*			*Feet.*	*Feet.*
Central Oregon Irrigation Co.'s north canal, Bend.	Trapezoidal.	12	......	25.7	0.883	.00095	0.221	240
		12	......	74.86	1.627	.000629	0.151	240
		12	......	98.3	1.952	.000525	0.124	240
Utah.								
Davis & Weber, near Ogden.....	Trapezoidal slopes 1 to 1.	22	2.70	208	2.24	.000409	......	....
		22	2.65	202	2.21	.000409	......	....
		22	2.70	201	2.27	.000409	......	....
		22	2.73	192	2.26	.000409	......	....
		22	2.34	162	1.98	.000417	......	....
		22	2.25	170	1.92	.00050	......	....
		22	1.60	122	1.43	.00050	......	....
		22	1.81	150	1.57	.00050	......	....
		22	1.49	102	1.31	.00050	......	....
		19	1.75	133	1.50	.000626	......	....
		19	1.13	68	1.01	.000626	......	....
		19	1.50	113	1.31	.000626	......	....
Davis & Weber Flume Canal, near Ogden.	Trapezoidal.	18.5	......	120.9	1.50	.000619	......	468.5
Do............................	.....do.......	19	2.34	212	2.07	.000629	0.629	1,000
South Cottonwood, Ward Canal, Murray.	Trapezoidal but nearly rectangular.	25±	......	2.86	.520	.000694	0.232	350
Washington.								
Sulphur Creek Wasteway, Reach No. 4, Sunnyside project, U. S. Reclamation Service.	Semicircular	[1] 4	......	52.5	0.69	.0205	18.46	900
		[1] 4	......	247	1.37	.0207	18.61	900
		[1] 4	......	242	1.36	.0206	18.57	900
Sulphur Creek Wasteway, Reach No. 6, Sunnyside project, U. S. Reclamation Service.	.....do......	[1] 4	......	52.5	.67	.0144	18.80	1,300
		[1] 4	......	45.0	.62	.0145	18.85	1,300
		[1] 4	......	247	1.33	.0144	18.71	1,300
		[1] 4	......	242	1.30	.0144	18.79	1,300
Montana.								
Hamilton Flour Mill, Hamilton..	Rectangular with fillet.	7	4.11	107.6	1.94	.00062	......	3,000
California.								
Lateral 12, Orland project, near Orland.	Trapezoidal with dished bottom.	4±	......	5.71	.543	.000990	0.204	206
Sanderfer Ditch Co.'s main canal, Whittier.	Trapezoidal.	2.5±	......	18.71	.842	.002376	1.812	743.3

[1] Radius.

elements, value of "C" in Chezy's formula and "n" in Kutter's formula—Continued.

Velocity feet per second.	C in Chezy formula.	*n* in Kutter's formula.	Method of measuring discharge.	Method of measuring slope.	Condition of surface, etc.	Remarks.	Reference and authority.
2.10 2.85 2.94	72.5 90.8 92.5	.0192 .0176 .0177	Vertical curve.	Level and hook gage.	Extremely rough concrete.	Tangent. Sharp curves adjacent each end and a very rough rock cut beginning about 200 feet below this section.	F. C. Scobey, Irrigation Investigations.
3.12	103	.0166	Current meter.	Level; grade of bottom for long lengths taken as slope of water surface.	Expansion joints 12 feet apart usually, some 8, 10, and 16 feet, made by inserting temporary wooden strips. Through neglect of management the wooden strips were not removed and asphalt inserted, but projected in some cases from 1½ to 2 inches above surface and impeded flow. These were more frequent in the upper portion. There was also some gravel on the bottom in the upper portion. Concrete placed without forms, finish of average smoothness.	Mean of 3 measurements.[1]	Unpublished records of Office Irrigation Investigations. Measurements by E. R. Barrett under direction of W. W. McLaughlin.
3.09	103	.0165				Mean of 5 measurements.[2]	
2.97	97	.0176				Mean of 6 measurements.[2]	
2.84	94	.0182				Mean of 3 measurements.[2]	
2.76	97	.0171				Mean of 3 measurements.[2]	
3.06	99	.0168				Mean of 5 measurements.[2]	
2.86	105	.0151				Mean of 4 measurements; depth 0.83 to 2.18.[2]	
3.16	112	.0142				Mean of 5 measurements; depth 0.8 to 2.27.[2]	
2.55	99	.0156				Mean of 5 measurements; depth 0.67 to 2.33.[2]	
3.89	110	.0144				Mean of 8 measurements; depth 0.85 to 2.45 [2]	
2.62	104	.0141				Mean of 7 measurements; depth 0.6 to 1.87.[2]	
3.25	113	.0138				Mean of 8 measurements; depth 0.6 to 2.29.[2]	
3.34	......	.0146	Vertical curves.	Level and hook gage.	Medium smooth concrete.	Wooden strips at joints projecting 1¼ to 1½ inches.	B. P. Fleming, Irrigation Investigations.
3.94	109.7	.0154	...do.....	...do.......	.....do...............	Wooden strips at joints projecting 1¼ to 1½ inches.	F. C. Scobey, Irrigation Investigations.
1.38	72.6	.0171	Current meter, integ.	...do.......	Rough concrete, influence disappeared through deposit of slime and moss.	Tangent with slight curve.	Do.
12.4 19.3 19.1	104.3 114.4 114.1	.0136 .0140 .0140	Current meter in main canal.	Level and hook gages in wells.	Concrete deposited against wood forms; no retouching of surface.	On 2° curve.......	Records of U. S. Reclamation Service.
13.1 12.5 20.4 20.6	133.1 131.7 147.8 150.5	.0109 .0109 .0110 .0108	..do.....	...do.......	.....do...............	Tangent............	
3.86	111.4	.0149	Vertical curves.	Level and hook gage.	Fairly smooth concrete.	Slight amount of moss, new flume.	S. T. Harding, Irrigation Investigations.
1.86	80.2	.0160	...do.....	...do.......	Fairly smooth cement finish.	Some gravel on bottom.	F. C. Scobey, Irrigation Investigations.
3.75	92.0	.0155	...do.....	...do.......	Smooth cement wash concrete.	Tangent roughened by a dark deposit.	Do.

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[1] Alignment contains many curves.

TABLE III.—*Measurements of flow in concrete-lined canals giving hydraulic*

Canal and location.	Shape of section.	Bottom width.	Depth.	Discharge.	Mean hydraulic radius.	Slope of water surface.	Total fall.	Length tested.
California—Continued.								
		Feet.	*Feet.*	*Sec.-ft.*			*Feet.*	*Feet.*
Santa Ana main canal, near Anaheim.	Trapezoidal.	10	......	27.16	1.215	.000321	0.328	1,082.8
Modesto Irrigation District main canal, near La Grange.	.....do.......	20	......	114.8	1.381	.001157	0.874	755.6
Arroyo Ditch & Water Co.'s main canal, near Whittier.	.....do.......	3	......	18.54	0.951	.001449	1.449	1,000
Los Nietos Water Co.'s main canal, near Whittier.	.....do.......	2	......	19.36	.983	.001444	0.971	600.5

elements, value of "C" in Chezy's formula and "n" in Kutter's formula—Continued.

Velocity feet per second.	C in Chezy formula.	n in Kutter's formula.	Method of measuring discharge.	Method of measuring slope.	Condition of surface, etc.	Remarks.	Reference and authority.
1.67	87.1	.0176	Vertical curves.	Level and hook gage.	Medium smooth concrete; 0.1 to 0.2 foot of sand in bottom; rough with hard deposit about ½ inch thick.	....	F. C. Scobey, Irrigation Investigations.
3.59	89.7	.0174	...do.....	...do.......	Fairly smooth concrete with no vegetable growth. Tangent.	A few loose rocks in canal and right angle turn below section accounts for high "n."	Do.
2.83	76.2	.0188	...do.....	...do.......	Rough finish with combined vegetable and mineral deposit.	Tangent...........	Do.
2.89	76.5	.0197	...do.. ..	...do.......	Fairly smooth cement finish roughened by a dark deposit.	Shifting sand on bottom.	Do.

Perhaps the most important conclusion to be drawn from the 76 measurements of the 18 canals summarized in the table is that the so-called coefficient of friction *n* is on an average larger than has usually been assumed by engineers. The results show that only in rare cases, where conditions are more or less ideal, is one justified in assuming a value as low as 0.012 for *n*. The Ridenbaugh Canal of the Nampa and Meridian irrigation district of Idaho, shown in Plate XVII, figure 2 (p. 80), belongs to this class. The flow in this concrete-lined canal has been measured by at least five engineers and their average result as regards the value of *n* is a trifle below 0.012. In the results given in the table, one also finds a value of *n* as high as 0.0197 and five others greater than 0.018. Again, in the concrete-lined canals of southern California a coating consisting of a vegetable and mineral accumulation was found adhering to the perimeters. The effect of this coating on the flow of water is seen in the high coefficient of friction for these channels as given in Table III. This coating may be observed in Plate I, figure 1, which shows a portion of the Santa Ana Canal near Orange, Cal.

The following approximated values for *n* may serve as a guide to those who are required to estimate, prior to construction and operation, the discharge of lined canals.

I. $n=0.012$ for concrete-lined canals having a smooth sidewalk finish, clean bottom, no moss, uniform cross section, well-formed joints, long tangents, flat spiral curves, no perceptible undulations on the surface of the water, and in general the best construction and the best conditions obtainable in practice.

II. $n=0.013$ for concrete-lined canals having conditions slightly better than those of Type III and not so good as those of Type I.

III. $n=0.014$ for concrete-lined canals having an unplastered or rough troweled surface, clean bottom, uniform cross section, well-formed joints, medium curvature, no spirals, slight surface undulations, no aquatic vegetation, and in general good construction and favorable conditions.

IV. $n=0.015$ for concrete-lined canals having conditions similar to those of Type III, but with greater curvature and some débris or other retarding influences.

V. $n=0.016$ for concrete-lined canals of average workmanship and medium conditions, having a rough surface, imperfect joints, and sharp curves; also for canals of smooth lining and good workmanship, but having one or more unfavorable conditions, such as sand and gravel in the bottom or projecting joints which decrease the velocity of water.

VI. $n=0.017$ for concrete-lined canals roughly coated, but otherwise in medium condition.

VII. $n=0.018$ [1] for concrete-lined canals coated as in Type VI and having the bottom more or less covered with sand and gravel, or else a clean bottom but poor alignment, irregular cross section, broken gradient, or the like.

OTHER KINDS OF LINING.

Experiments were made by this office in 1906 in cooperation with the University of California [2] to determine the cost and relative merits of different kinds of canal lining. A series of short experimental ditches were excavated in a field in Stanislaus County, Cal., about 4 miles east of the town of Modesto. The channels used were 50 feet long, had a bottom width of 2 feet, a depth of 2½ feet, and a slope of 1½ to 1 on both sides and ends.

The experiments were continued under the direction of the writer the year following on the same site, and a similar set of experiments were also conducted on the university farm at Davis, Cal. The results obtained in 1907 at both sites did not agree with those published in the progress report and in consequence the final report was not published. The belief is quite general, however, that the report of the results obtained in 1906 [2] tended to give erroneous impressions as to the relative merits of certain kinds of linings. This is especially true of oil lining. The Lemoore Canal & Irrigation Co. of Kings County, Cal., was cited as an example where heavy crude petroleum containing a high percentage of asphaltum had been successfully used in lining 1½ miles of their main canal. It would appear that this experiment did not prove altogether satisfactory since the company which tried it has discontinued the use of this kind of lining. Other investigations have shown that oil lining is not effective for a long period of time. Even in California where a heavy oil containing a large percentage of asphaltum can be purchased for about 2 cents per gallon, practically no canals have been lined, to the writer's knowledge, with this material in the past five years.

When lumber was cheap and cement expensive it was common practice in the West to line the weak and leaky portions of canals with lumber in the form of flumes. The short life of wood, particularly where it is in contact with moistened earth and exposed to the air, the high cost of maintenance, the high cost of lumber, and the somewhat lower cost of cement have all tended to lessen the use of wooden lining.

Reference has already been made to the advantages of a natural lining of silt derived from the earthy impurities borne by the water in the canals. A clay puddle may likewise serve as an effective barrier against the escape of water. If the bottom of a new canal in porous material is covered with a layer of clay, moistened, and then used as a feeding ground for domestic animals it may be rendered quite impervious. Some of the thoroughly worked clay can afterwards be removed from the bottom and placed on the slopes. When domestic animals are not available to mix the clay, it should be done by harrowing and packing. A layer of coarse gravel spread over the clay lining and tamped into it may prevent the erosion of the clay and render it more effective.

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[1] The value of n for some concrete-lined canals exceeds 0.018. In such cases, however, the increased carrying capacity due to lining is counterbalanced or nearly so by deposits of débris in the bottom, aquatic vegetation, or other causes.

[2] California Sta. Bul. 188 (1907).

THE ECONOMY OF CONCRETE LINING.

In determining the economy of concrete lining for a given canal, one has to consider and compare the cost and benefits of such work. Itemized statements of the cost of concrete lining for various canals are given in another part of this report. The principal benefits to be derived from lining are briefly discussed under the following heads:

(1) *Seepage water and its value.*—The possible saving in seepage losses by lining can be readily determined for canals already in use, and the portions in which this is important can be located by measurements of the discharge. In some cases the loss in short distances may be sufficient to make the lining of these desirable, although it would not be practicable to line the canal as a whole.

In the case of a new canal, a reasonably close estimate of the seepage losses which are likely to occur may be made from the data given in Table I.

In nearly every irrigated district of the West water which can be saved through the prevention of seepage has a value. As the demand for water increases the value of any saving will also increase until methods of canal lining at present too expensive to be considered may become practicable. The value of the water which may be saved varies widely in the different portions of the country. On the larger systems now being constructed, water rights are being sold for from $25 to $50 per acre, and in some cases for even higher prices.

Based on the final estimated cost and acreage included, the average estimated cost per acre July 1, 1910, was $48.14 for the United States Reclamation Service projects and $21.75 for the Carey Act projects. The duty of water delivered under these rights is also variable and will probably average 1 second-foot to 100 acres. Inasmuch as any saving in canal seepage can be delivered to the user with small additional loss, each 0.01 second-foot saved should make it possible to serve another acre. The additional expense required for such irrigation would be for the lateral system only, as the storage and diversion works would not be affected. On this basis each second-foot of water which can be saved should have a value of from $2,500 to $5,000. Allowing $750 for the additional cost of the distributing system leaves

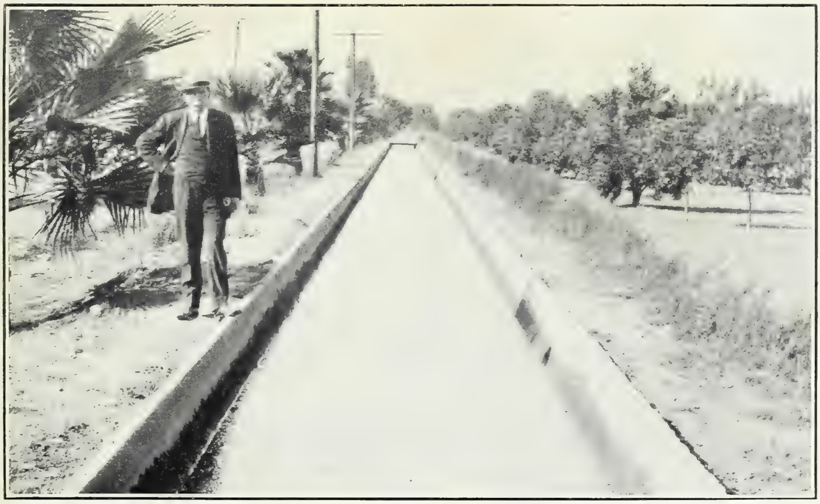

FIG. 1.—SANTA ANA CANAL NEAR ORANGE, CAL.

(Showing moss and mineral accumulation on wetted surface.)

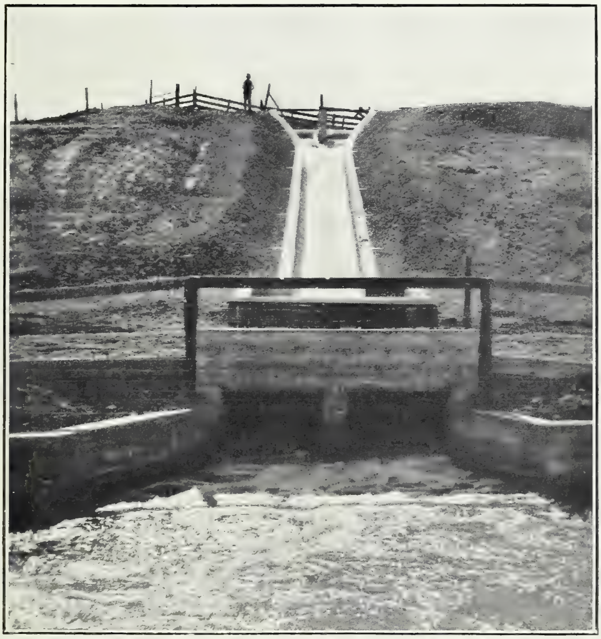

FIG. 2.—BY-PASS CHUTE, ORLAND PROJECT, U. S. RECLAMATION SERVICE, ORLAND, CAL.

(From a photograph furnished by A. N. Burch, project manager.)

$3,000 as a general average for the value of each second-foot saved by lining.

(2) *Increase in carrying capacity.*—The volume carried by a canal in earth is as a rule much less than that carried by a concrete-lined canal of the same dimensions and grade. This is due to the smoother perimeter of the latter, and its greater uniformity in cross section, alignment, and grade. The discharge of a typical canal in earth having a mean velocity of 2.5 feet per second and a coefficient of friction (*n* in Kutter's formula) of 0.0225, may be increased from 25 to 80 per cent by lining with concrete. A gain of 25 per cent in the volume carried is readily obtained as the result of lining, but to secure a gain of 80 per cent involves the construction of first-class lining and conditions favorable to the maximum discharge of water in such channels.

(3) *Reduction of charge for operation and maintenance.*—On many systems, particularly where the canal follows a side hill, much difficulty is encountered from breaks on the lower bank when the canal is crowded to its full capacity or when an opening may be made by a gopher or other burrowing animal. A concrete lining should prevent such breaks except in cases where the water overtops the bank due to stoppage or other causes. Faulty location of the canal and weak places developing later can very often be largely corrected by a good concrete lining. Where the original grade is such that scour occurs, or where excessive curvature causes cutting of the sides, a similar remedy may be used. Maintenance charges also will be materially reduced by the lessening of weed growth and the prevention of the shifting of the channel through scouring. In some systems the fall of the country is too great to be taken up by the grade of the canal and many drops are required which may form a considerable proportion of the cost and necessitate high maintenance expenses. The use of a concrete lining frequently permits a sufficiently high grade to be used so that no drops are needed, the saving in these structures paying part of the cost of the lining.

(4) *Insurance against damage to crops.*—As the losses from the lack of water at critical times during the irrigation season are often much greater than the actual cost of repairs, a portion of the cost of any canal lining may be considered as an insurance against such accidents. An instance of this occurred on the Turlock Canal, of California, in 1910, when a break thought to have been due to a gopher hole caused 1,000 feet of the main canal on a steep side hill to be washed out. The canal was out of service for six weeks during the period when water was most needed for crops. The actual cost of repairs was $20,000, but the estimated damage to crops was $1,000,000.

SUITABLE GRADES FOR LINED CANALS.

In deciding upon suitable grades, cross sections, and alignment for lined canals, one has to take into account the two types of canals which are lined. One of these is represented by the canal in operation designed for earth, the other by the new canal designed for concrete lining.

The grade which is suitable for a canal in earth is not the most economical grade for the same canal when lined with concrete. It is not, however, feasible to make any material change in the grade of an old canal preparatory to lining it. The irregularities can and should be removed so as to secure a uniform gradient, but more than this can not be done without changing the location.

The discussion of suitable grades must therefore be confined in this report to new canals intended to be lined before carrying any large percentage of their maximum capacity. Disregarding all other features and considering only the most economical method of conveying water, the steep grade with its correspondingly high mean velocity is best. The fact is now fairly well established that water can pass over a concrete surface at a high velocity without injurious effects. It is only when fast-flowing water strikes against concrete or is obstructed by it that damage is likely to result. Mr. A. P. Davis, chief engineer of the Reclamation Service, cites a case[1] in which a concrete chute on the south canal of the Uncompahgre project, discharging 300 cubic feet per second at a velocity of over 20 feet per second for one year, not only showed no perceptible wear, but it had acquired a growth of slimy moss over the concrete surface subject to this velocity.

In the summer of 1913 Justin T. Kingdon, of this office, made an examination of a concrete chute (Pl. I, fig. 2) on the main canal of the Orland project, Orland, Cal. The canal maintains a fairly constant flow throughout the season. It was measured shortly after the observation and found to be discharging 84 second-feet of water which at the bottom of the chute had a velocity of 17 feet per second, and like the south canal of the Uncompahgre project, this concrete showed no wear on its wetted area, and the growth of slimy moss which it had acquired was especially noticeable over that portion of the surface subject to the highest velocity.

It would therefore appear that the permissible velocity in lined canals depends largely on considerations other than damage to the lining. The mention of three of these causes may serve to make this statement clear. Assuming that a concrete-lined canal will successfully withstand velocities up to 20 feet per second, the fall necessary to produce such velocities must be considered, since the sacrifice of so much head might entail greater cost than the building of a larger canal on a lighter grade.

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[1] Eng. News, 67 (1912), No. 1, p. 20.

Again, the extra cost and inconvenience in making suitable turnouts to divert water from such a canal would serve to lessen the advantages gained by having a high velocity.

Lastly, pulsations are a common feature in all channels in which the water flows at a high velocity. The water surface consists of irregular waves which travel at various distances apart and an extra height of lining is required to prevent the waves from overtopping it.

It is believed that a mean velocity of between 8 and 10 feet per second is about as high as should be adopted in lined canals under ordinary conditions.

ALIGNMENT OF LINED CANALS.

In locating a new canal for concrete lining, sharp curves should be avoided if possible. The reduction of curvature in a location over a rough country with steep slopes may increase considerably the amount and the cost of excavation, but this additional expense may be more than compensated by the advantages gained in having flat curves.

In flowing around curves the surface of the water tends to rise on the outer side due to centrifugal force. The height to which it will rise in any given case will depend on the velocity of the water and the sharpness of the curve. In order to maintain a uniform height of lining above the water surface of the canal, the practice has been to raise the outer lining. In the case of the Tieton main canal of the United States Reclamation Service, Yakima project, Washington, on the sharpest curves, having a radius of 57.6 feet and a velocity of 9 feet per second, the superelevation amounted to about 1 per cent of the width.

The presence of a large number of sharp curves likewise increases the cost of both the earth trimming and the laying of the concrete.

In railroad location it is customary to limit the curvature within a certain fixed maximum regardless of expense, but in the construction of irrigation canals, on account of the wide range permissible, it has not been customary to fix any such limit. The expense of excavation required to lessen curvature should be balanced against the disadvantages and extra cost of lining sharp curves.

THE EFFECT OF ALKALI ON CONCRETE LINING

Throughout the West are to be found here and there instances of concrete construction having been disintegrated through the action of alkali salts. While some uncertainties remain regarding the exact nature of such action, there seems to be no question but that the principal reason for it arises from the reaction between the various alkali salts and the calcium hydroxid of the cement. The new compounds formed have a greater volume than the replaced hydroxid and their formation weakens or destroys the concrete by forcing apart the particles of cement. In order for this action to occur it is necessary for the water containing alkali to percolate into or through the concrete. Under field conditions[1] "these reactions referred to are much retarded if not entirely suspended in most cases, due probably to the carbonization of the lime of the cement near the surface or the formation of an impervious skin or protective coating by saline deposits."

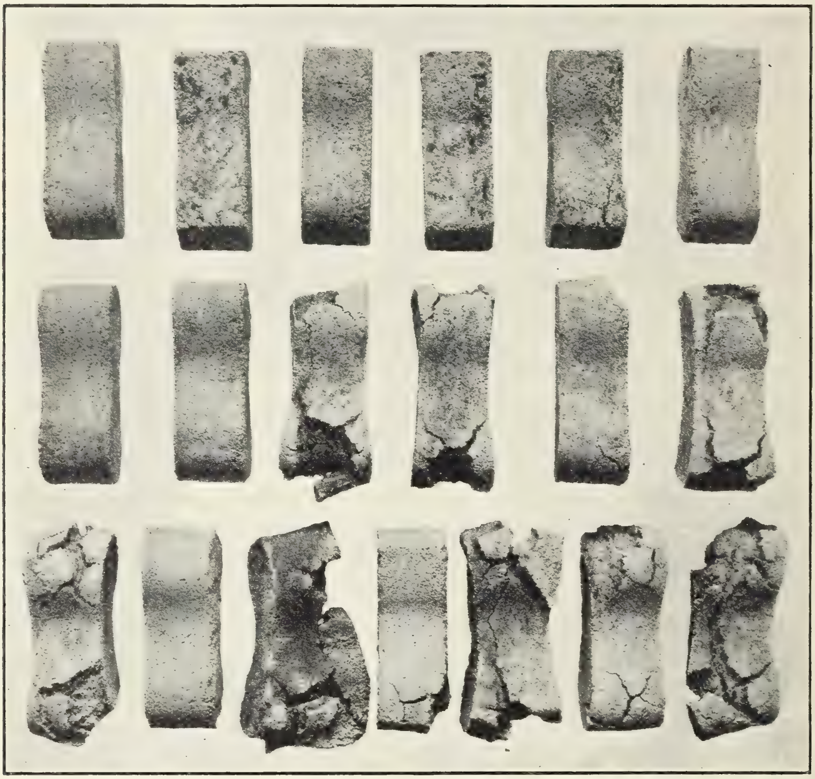

FIG. 1.—Briquets showing repellent action of oil-cement concrete on alkali water. (From tests by the Office of Public Roads, United States Department of Agriculture.) Top row contained 10 per cent of semiasphaltic oil; middle row contained 5 per cent of semiasphaltic oil; bottom row contained no oil. Briquets were immersed one year in a 10 per cent solution of sodium sulphate.

It is also doubtless true that[2] "wetting and drying or freezing and thawing will hasten the destruction of the cement by extending the cracks already started."

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[1] U. S. Dept. Com., Bur. Standards Technol. Paper 12 (1912).

[2] Montana Sta. Bul. 81 (1910).

In experiments with oil-mixed Portland cement concrete,[1] the concrete was damp-proofed by the incorporation of semiasphaltic oil. In hand mixing, the sand, cement, and water were first mixed to a mushy consistency, the oil added and mixed until no trace of it was visible on the mortar surface, and then the broken stone or gravel was mixed in. In machine mixing the sand, cement, and water were first mixed to a mortar followed by alternate batches of stone and oil which were added and mixed. The proportion of oil used was based on a comparison of its weight to the weight of the cement used in the concrete. The results of tests show that oil-mixed mortar, containing 5 to 10 per cent of oil, is dampproof as well as waterproof, and indicate that its use may prove desirable in the construction of irrigation canal linings exposed to the action of alkali (fig. 1).

Good practice in concrete lining construction where alkali must be reckoned with necessitates the following precautions:

(1) Do not use sand, gravel, or water containing alkali.

(2) Keep soil waters charged with alkali from coming into contact with the concrete by the use of suitable drainage.

(3) Give careful attention to the proper proportioning of materials and use more cement than is needed to fill the voids.

(4) Protect the surface by a thin plaster coat of dense mortar of granular sand.

(5) Both the concrete and the mortar used for the lining may be dampproofed by the addition of 5 to 10 per cent of semiasphaltic oil when mixing the materials.

THE EXPANSION AND CONTRACTION OF CONCRETE.

FIELD TESTS AT LOGAN, UTAH.

During the summer of 1913 field experiments were conducted by Prof. B. P. Fleming, of the State University of Iowa, working under the direction of this office, at Logan, Utah, for the purpose of determining the coefficient of expansion of concrete slabs. An effort was made to secure conditions as nearly as possible like those found for canal linings. It will be noted, however, that the slabs were not tested to find the effect produced by being wet on one side.

The variations in length were measured with two micrometer microscopes focused upon lines in the highly polished tops of two steel pins projecting above the surface of the slab, one at each end. This device permitted making direct readings from the micrometer scale, giving measurements to 0.0008 of a millimeter. The thermometers used were graduated to 0.10° C. and could be estimated easily to 0.025°. All measurements of the slab length were direct, and no part of the apparatus was in contact with the slab. The idea of maintaining the latter condition was to prevent in every possible way influences which might affect the expansion of the slab.

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[1] U. S. Dept. Agr., Office Pub. Roads Bul. 46 (1912).

Except for a roller placed under one end, each slab was lying on ground composed mostly of loose gravel.

The slabs were 12 inches wide, 6 inches deep, and 11 feet long. The steel pins inserted vertically in the top were spaced 10 feet apart, thus leaving 6 inches length of slab beyond the pin at each end. A wet hand-mixed concrete mixture was used for each slab, numbered 1 and 2, and volumetrically proportioned 1:3:5 and 1:2:4, respectively. Each slab was of rectangular cross section throughout.

The general average coefficient of expansion measured was 0.0000043 for slab 1 and 0.0000042 for slab 2.

LABORATORY TESTS AT THE STATE UNIVERSITY OF IOWA.

In the fall and winter of 1913–14 the experimental work initiated at Logan, Utah, was continued in the laboratory of the State University of Iowa under the same supervision as before.

The sand and gravel used were taken from the bed of Iowa River. This raw material was screened through a 1-inch mesh screen and again through a $\frac{1}{4}$-inch mesh screen. The material failing to pass the latter screen was considered gravel. The sand was unscreened, but it was fine and clean.

Three horizontal slabs were cast with the same dimensions as those made at Logan. The apparatus and equipment were practically the same, except that the laboratory permitted a somewhat careful control of influencing conditions not possible in the open-air work. In addition, a specially devised apparatus permitted the making of observations for change of length within 30 minutes after water had been added to the dry materials used in making the concrete. Brass pins with their upper ends highly polished were used instead of steel pins. The methods employed for temperature determination and control were quite satisfactory and it is believed gave results fully as accurate as the investigations warranted.

Two slabs of seasoned concrete were used for determining the coefficient of expansion. A third one was used to determine the influence on change of length due to setting. Each slab was made of hand-mixed concrete, using the materials composing the concrete in the following proportions:

Proportions of materials used in making concrete slabs.

Mixture.	Number of slab.		
	1	2	3
By volume:			
Cement	1	1	1
Sand	3	2	3
Gravel	5	4	5
By weight:			
Water	100	72	75
Cement	118	99	79
Sand	319	203	244
Gravel	552	441	431

The general average coefficient of expansion measured was 0.00000627 for slab 1 and 0.00000632 for slab 2.

Slab 3 was kept at a temperature of about 80° F., though at times it fell to 70° and even 65° during Saturdays and Sundays. Daily observations were made early in the work, but later on observations were made only once a week. It is interesting to note (fig. 2) the immediate and rapid expansion following pouring, lasting about one week. This caused a change of length of about 0.00012 foot per foot. This action was doubtless due to the physical rearrangement of the particles of concrete in the process of crystallization. So far as its effect upon concrete lining for canals is concerned, if joints were not provided, it would cause severe compression of the slab as a whole for about a week or 10 days, which might cause a slight buckling and crushing. Where joints are used and filled with asphaltum or similar material the tendency would be to force some of it out of place, and for this reason the filling material should not be placed until about two weeks after the lining has been laid. It will be noted, however, that the expansion is only 0.012 foot in 100 feet, which accounts for its effect being of no marked importance in practice.

It will also be noted (fig. 2) that following the expansion period in slab 3 there is a period of contraction lasting about 75 days and during which there is a total contraction at the rate of about 0.042 foot in 100 feet, thus leaving the slab 0.03 foot shorter for a 100-foot length than when laid. If this factor were considered for a concrete lining, assuming that its contact with the material through which the canal were constructed would not retard the expansion, having a coefficient of expansion of 0.0000045, it would allow a total rise of temperature of about 67° F. before two adjoining slabs would be in contact after the contraction due to setting had been completed. It is evident, therefore, that if a slab were laid in the winter at a temperature of 40° F., the joints opened by contraction would not be closed until the slab had reached a temperature of 106° F. in the summer. Concrete lining is usually placed in canals during the winter or at least when the weather temperatures are cold enough for the above conditions to obtain. If the water carried in the canal is at a temperature of between 40° and 60° F., it is evident that the effect of contraction in concrete lining laid at corresponding temperatures will be most noticeable at a time when water-tightness is most desired. For this reason it is essential that some provision be made to secure water-tight joints. It may also be quite necessary to use some elastic material like tar paper to allow for expansion in excess of that which can be taken up by the space formed due to contraction in setting, for in some sections of the West temperatures are likely to be met which will cause this extra expansion, and unless a compressible material is provided buckling or crushing is very likely to occur.

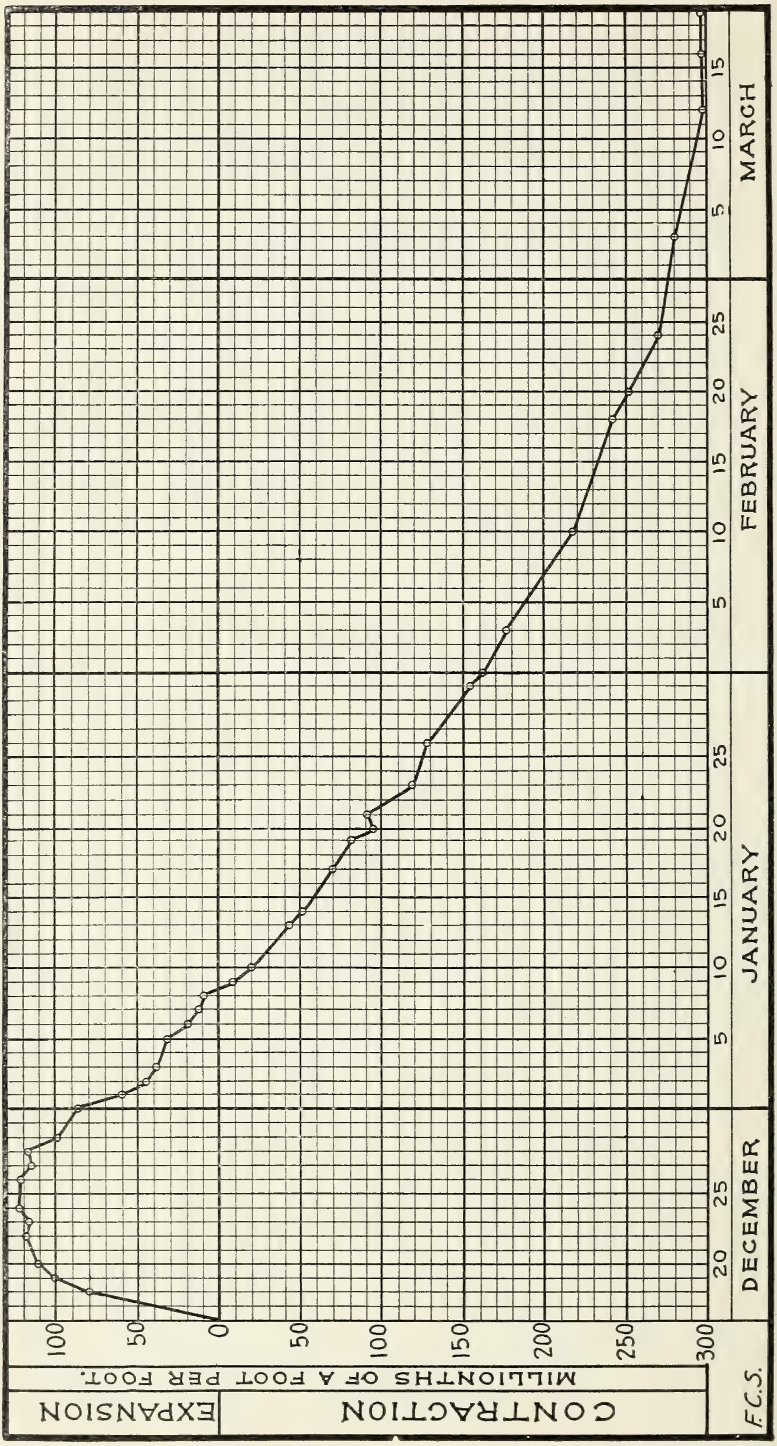

FIG. 2.—Curve showing expansion and contraction of concrete from actual measurements made on a 10-foot length of slab (measurements commencing within 30 minutes of time water was added to aggregate.)

In summing up the results of the experiments at Logan, Utah, and those at the State University of Iowa, it may be stated that for concrete slab construction such as canal lining, where only one side is exposed and with the other side in contact with earth, a coefficient of expansion of 0.0000045 should be used, but in the case of concrete construction where all sides are subject to equal temperatures and are not under the conditions of moisture and earth contact found in canal lining and similar construction, a coefficient of 0.0000063 can be used with safety.

JOINTS IN CONCRETE LINING.

Owing to the fact that concrete lining expands in warm weather and contracts in cold weather, joints would seem to be an essential feature of such construction. Where no provision is made for expansion and contraction by means of joints, the concrete lining is certain to be subjected to high internal stresses, which increase in intensity until the lining is ruptured. These ruptures occur at the weakest points, and following the directions of least resistance result in irregular fractures which are difficult to repair. They frequently are so small and so irregular that it is practically impossible to introduce any filler into the seams. Even when this is done the alternate opening and closing of the fracture, due to changes in temperature, lowers and in time destroys the effectiveness of such repairs.

On the other hand, joints in concrete lining constitute a weak feature. In strength, durability, and water-tightness the best formed joint is inferior to the continuous lining. For these reasons, to which may be added that of extra cost, the distance between joints should be as great as possible consistent with changes in volume due to temperature and the adoption of suitable forms and proper methods of construction.

When forms are used their length is usually limited to the size and weight which can be readily shifted by hand without the aid of special equipment. Even when the forms are of the simplest kind the methods of construction commonly employed place other limitations on the distance between joints. Again, in lining curves the frequency of the joints depends upon the degree of curvature, the sharper the curve the shorter the distance between joints. Notwithstanding these limitations, the tendency in the past has been to insert too many joints, particularly on straight portions of canals.

The subject of joints in concrete lining is also closely related to the manner in which the lining is laid, whether continuously or in alternate sections. Joints which are adapted to one of these methods may be a misfit when applied to the other. In using either method it is advisable to break joints between the floor and the sides, as indicated in figure 3, *a*.

KINDS OF JOINTS.

Various kinds of joints are used to prevent cracks in concrete linings:

(1) One of the most common is the plain abutting joint. This joint is simple, cheap, and easily made. Expansion, likewise, is provided for in the frequency of the joints. It has, however, several weak features which render its use questionable. One of these is the lack of any bond between the sections. Were it not for the connection with the bottom at the toe each side section might be regarded as a separate slab, liable to be thrust upward by pressure from behind or to fall backward when the earthen support is removed. Both of these effects are quite probable, and may be seen in the lining of the New York Canal of the Payette-Boise project (fig. 4). Another defect is the difficulty experienced in filling the seam with any material which will render the joint water-tight, it being too narrow to calk.

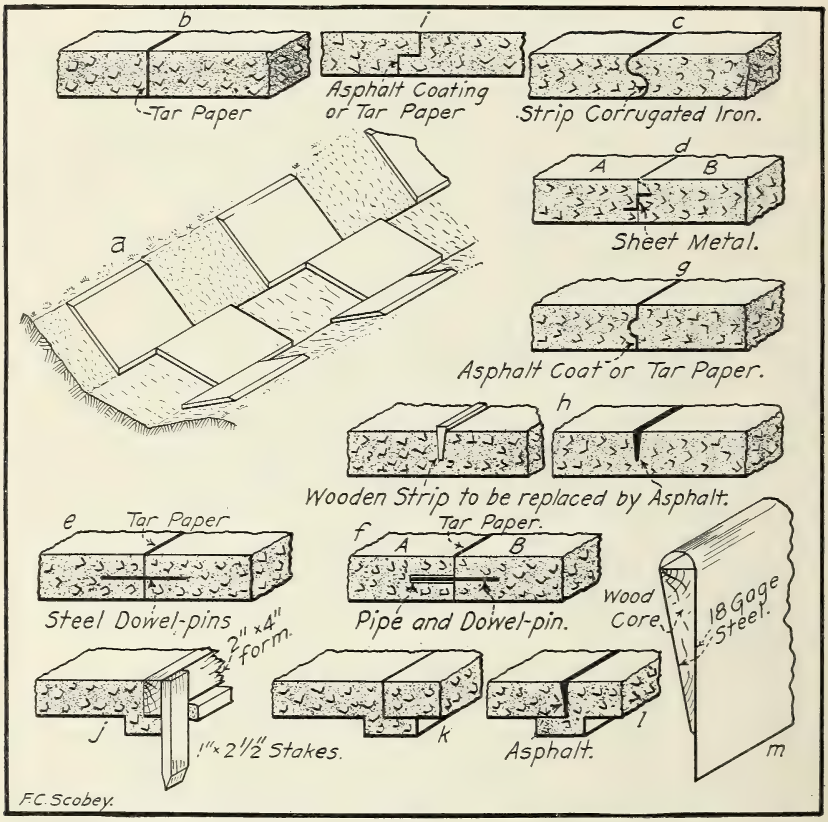

FIG. 3.—Typical joints for concrete-lined canals.

(2) The abutting joint is frequently modified by introducing one or more plies of tar paper (fig. 3, *b*). While the paper provides for

extra expansion and renders the joint more impervious, it adds nothing to the bond between the sections.

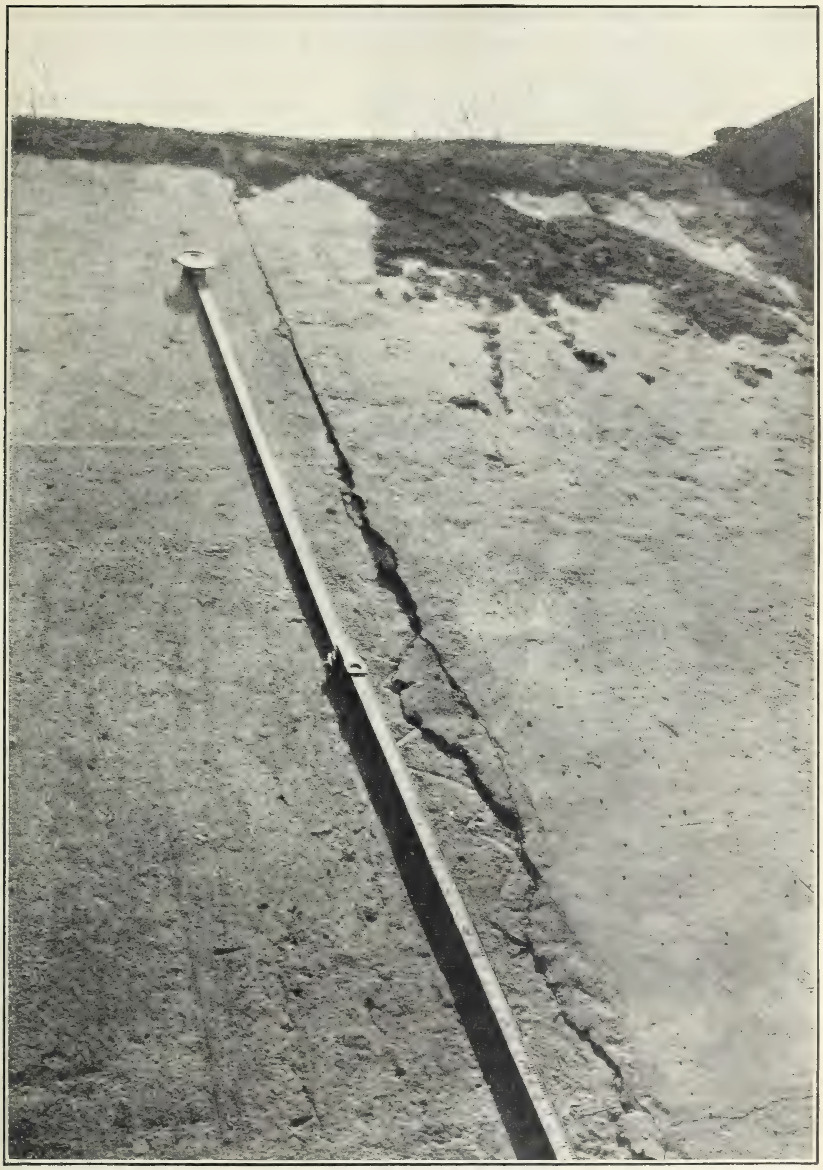

FIG. 4.—A broken joint in concrete lining, New York Canal, Boise, Idaho.

(3) An interlocking device (fig. 3, *c*), consisting of a 4-inch strip of corrugated iron, was inserted in each joint of the lining of the North Side Twin Falls Canal, Idaho. If the metal strip is thickly

coated with asphalt before being inserted it may prevent leaks. The device likewise secures a fairly good bond.

(4) A pliable metal sheet protected from rust, of the form shown in figure 3, *d*, has also been used for such purposes. When section A is being laid the metal assumes the form of a right angle, the vertical part being placed against the form. Before section B is laid the upper portion of the vertical is bent down to a horizontal position, as shown.

(5) In the Ridenbaugh Canal of the Nampa and Meridian irrigation district, Idaho, tar paper was inserted between the abutting joints, which are spaced 16 feet 3 inches apart, and a good bond between the sections was secured by short ½-inch steel rods (fig. 3, *e*).

(6) To overcome the objection of projecting rods in laying by the method just described, the plan of bonding shown in figure 3, *f*, has been devised. A socket is formed in section A by means of a short ½-inch pipe, and into this is inserted one end of a steel rod five-sixteenths inch in diameter and double the length of a pipe. This contrivance adapts the joint to the alternate method of laying, as illustrated in figure 3, *a*.

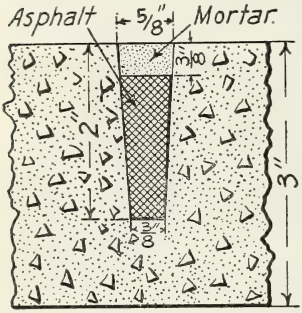

FIG. 5.—Sketch of joint used for concrete lining, Patterson Land & Water Co., Patterson, Cal.

(7) The form of joint used by the writer on the Snake Ravine retaining walls of the Turlock irrigation district of California is shown in figure 3, *g*. In laying the lining in alternate sections the joint with its concave surface may be coated with hot asphalt or lined with tar paper before the adjacent section is laid.

(8) In lining the Davis and Weber Counties Canal in Utah, a thin strip of wood coated with asphalt was placed in each joint and extended through about two-thirds the thickness of the lining. The specifications called for the withdrawal of these strips and the filling in of the spaces with hot asphalt, but this was not done. As a result, many of the wooden strips became loose and project more or less above the surface of the lining, thus retarding the flow of water. In other respects the joint has proved satisfactory. (See fig. 3, *h*.)

(9) A somewhat similar joint (fig. 5) was used by the engineers of the Patterson Land & Water Co. and the East Contra Costa Irrigation Co. On both canals, to which references are made elsewhere, the wooden strips were removed and the spaces filled with hot asphalt to within three-eighths inch of the surface, the remaining space being filled with cement mortar. When inspected by the writer during construction he questioned the advisability of so wide a joint, and was advised that a smaller joint could not well be filled with asphalt.

(10) Where conditions are adapted to its use, the type of joint shown in figure 3, *i*, possesses some advantages over those previously discussed. This is merely the carpenter's shiplap or half-timber joint applied to concrete. It provides for all the expansion necessary without weakening the lining by too wide a joint space. It also permits a certain amount of "creeping" in the section without misplacement and furnishes an excellent opportunity to secure a watertight joint by the use of an elastic material like asphalt.

(11) In adapting the shiplap joint to thin concrete linings a greater thickness of lining is used at each joint. The sections shown in *j*, *k*, *l*, and *m*, figure 3, represent this modification showing two joints and methods of construction, as designed by A. F. Parker for the lining of the Davis and Uinta Counties Canal in Utah.

CONSTRUCTION METHODS AND COST.

In submitting the following data an effort has been made to show as fully as possible what constitutes current practice throughout the West in the lining of old and new canals. The lack of space prevents taking up many of these features in detail, but it has been the aim to select representative work in the various localities and to point out not only the good features of such work but to call attention to doubtful practices in order to assist the engineer in the design and execution of similar construction elsewhere.

PATTERSON LAND & WATER CO., PATTERSON, CAL.

About three years ago a series of pumping plants was installed to raise water from the San Joaquin River to irrigate a tract of 14,000 acres, comprising the bulk of what is locally known as the Patterson ranch. To prevent the loss of water by seepage the canals of this system were lined with a 3-inch layer of concrete and finished with a ¼-inch plaster coat.

The main canal at the river end (Pl. II, fig. 1) has a bottom width of 7 feet, a vertical depth of 5½ feet, side slopes of 1½ to 1, and a capacity of about 110 second-feet. Its capacity is reduced at various points along its length, and at a distance of 2½ miles from the intake the bottom width is 4½ feet.

After the excavation of each division the main canal was filled with water and allowed to soak for from 6 to 9 days. It was then trimmed and lined in 12 foot sections. The gasoline-driven concrete mixer had a capacity of 75 cubic yards per day, which provided material to line 300 linear feet. The position of this mixer when operated and the methods employed in elevating the material and delivering the concrete are shown in Plate II, figure 2. The concrete used was a mixture of 1 part cement to 6 or 6½ parts of sand and gravel. The plaster coat was proportioned 1:2 cement and river sand.

EAST CONTRA COSTA IRRIGATION PROJECT, BRENTWOOD, CAL.

This enterprise, although much larger, is similar in design, purpose, and scope to that at Patterson. Mr. A. Kempkey, the engineer in charge, in writing of this project claims that some improvements have been introduced in the lining as planned over the lining used on the Patterson project. One of these is the insertion of two expansion joints at the toe of each slope and parallel to the canal axis. It is also proposed to apply the mortar coat by means of a cement gun, at an estimated cost of 1 cent per square foot of surface.

The expansion joint used on both projects is shown in detail in figure 5, page 60. It has given good satisfaction wherever used in both canal and reservoir lining. A medium grade of asphalt, applied warm enough to flow readily but not smoking hot, is considered best to fill the joints. In using this joint it is not necessary to place the lining in alternate sections, as a tapering strip of wood may be inserted between adjoining sections. These strips can be afterwards removed and the joints formed by pouring asphalt into the grooves and applying a ½-inch coat of plaster on top of the asphalt. Plate III, figure 1, shows the work of lining this canal in progress and in Plate III, figure 2, is shown a portion of the completed canal lining.

NORTH SIDE TWIN FALLS LAND & WATER CO., MILNER, IDAHO.

This company lined 8,400 feet of its main canal to increase its capacity. The canal is carried for several hundred feet along a rough lava rock cliff and is 60 feet above low water in the river. The outer bank through this section is a concrete retaining wall. The remainder of the lined section is excavated almost wholly in solid lava. The grade varies from 0.001 in narrow places to 0.0002 and 0.00025 in the wider sections.

The canal was emptied October 10, 1909, and the work of preparing it for the concrete was commenced as soon as the channel had dried sufficiently. In places for several hundred feet from the headgates the canal bed was considerably below grade. The rock projecting into the canal section in the sides and bottom was blasted and smoothed, the low places being filled to subgrade with broken stone and puddled earth.

An 8-inch thickness of concrete was applied to the sides of the rock sections and a 6-inch thickness to the bottom. The sides of the rougher rock sections were riprapped to secure a better alignment and to save concrete. Cavities and large irregularities were back-filled with stones and puddled earth. It seems to the writer that the 6-inch thickness laid on the bottom of rock sections might have been reduced to 3 or 4 inches if the bed had been better prepared by the placing of finely crushed stone, compressing this material by rolling to secure an even surface and uniform grade, as is done in macadamized road construction.

The concrete was composed of a 1:3:6 cement, sand, and crushed stone mixture, but whenever a well-graded crushed stone could be secured sand was omitted and the concrete was made of 1 part cement to 6 parts crushed stone from which all particles over 1½ inches in diameter had been excluded.

In earth sections the lining of the sides and bottom was 4 inches thick and had side slopes of 1¾ to 1. Expansion joints of corrugated iron were inserted every 16 to 20 feet along the sides and bottom except in the bottom of the rock sections. These joints consisted of pieces of corrugated iron cut into strips 4 inches wide containing 1½ corrugations, these being designed to lock the edges of adjacent sections and to prevent slipping. (See fig. 3, *c*.)

The side walls in the rock sections were supposed to have a slope of 1 to 4; but in many places where this would have necessitated the blasting of large amounts of rock, walls were made almost vertical. Heavy, collapsible forms of 2-inch lumber were used in placing concrete for the walls which approached the vertical. The concrete was wheeled directly from the mixers and spread in uniform layers 4 inches thick over the bottom and on the sides of the easier slopes in earth sections. Concrete placed within forms made of 4 by 4 inch lumber was compacted by tamping and finished by working 24-foot floats made of 2 by 6 inch timbers back and forth over the upper surface of the forms. Sixty cubic yards of concrete per day were sometimes laid in this way by one gang working under favorable conditions. The sides and slopes were finished with a coat of cement mortar whenever the surface was rough enough to warrant it.

The unusually high cost of this work was largely due to the difficulty of preparing the rock cut for the lining and to the absence of sand and gravel, which made it necessary to crush rock for the concrete. However, a greater factor than either of these was the added expense due to the necessity of prosecuting the work during severe winter weather. To do this the canal was roofed over for a distance of 2,000 feet and the inclosed space warmed by specially constructed heaters, using sagebrush for fuel. The nature of the temporary roof and the method of heating are shown in Plate IV, figures 1 and 2. The cost of labor and material was as follows:

Cost of labor and materials for lining Twin Falls North Side Canal.

Laborers, per day of 10 hours	$2.50
Drillers, per day of 10 hours	2.75–3.00
Engineers (steam), per day	3.00–4.00
Man and team, per day	5.00
Coal per ton, f. o. b. Milner	6.50
Cement per barrel, f. o. b. Milner	2.59–2.89
Cost of crushing rock, per cubic yard	1.10
Cost of labor for placing concrete, per cubic yard	2.75

Complete cost of material, mixing and placing concrete for form work only, per cubic yard	$8.50
Same without forms	7.50
Cost of rock excavation (light cuts from 0.4 to 2 feet), per cubic yard	5.00
Cost of placing riprap 1 foot thick, per cubic yard	2.00
Total cost of preparing 8,400 linear feet of canal for concrete	75,000.00
Gross cost of lining 8,400 linear feet of canal	200,000.00
Average cost of concrete, per cubic yard	8.00

MAIN SOUTH SIDE, OR NEW YORK CANAL, UNITED STATES RECLAMATION SERVICE, BOISE, IDAHO.

This canal is designed essentially to carry flood water from a point on the Boise River 9 miles above Boise to the Deer Flat reservoir, a distance of 36 miles. Seventy thousand acres of land is also watered from the canal before the reservoir is reached. About 6½ miles of the canal was lined to prevent seepage, increase the carrying capacity, and for the safety of sidehill sections where breaks frequently occurred.

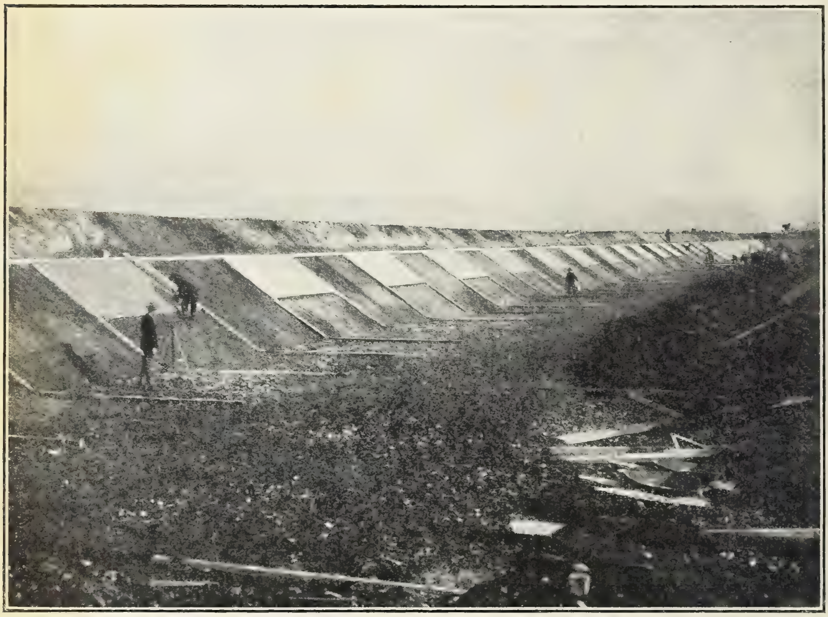

FIG. 6.—Showing method of setting forms on slopes for placing concrete lining in Main South Side, or New York Canal, U. S. Reclamation Service, Boise, Idaho.

The canal is an old one, originally built with side slopes of 1½ to 1, but the change and filling up of the section common to old canals necessitated considerable preliminary work in the removal of very gravelly earth and in shaping the sides before the concrete could be laid. The lined section has a grade of 0.00025 to 0.00032 and slopes of 1½ to 1. Forms of 4 by 4 inch lumber were placed upon the slopes and aligned, as may be seen in figure 6, after which the surface

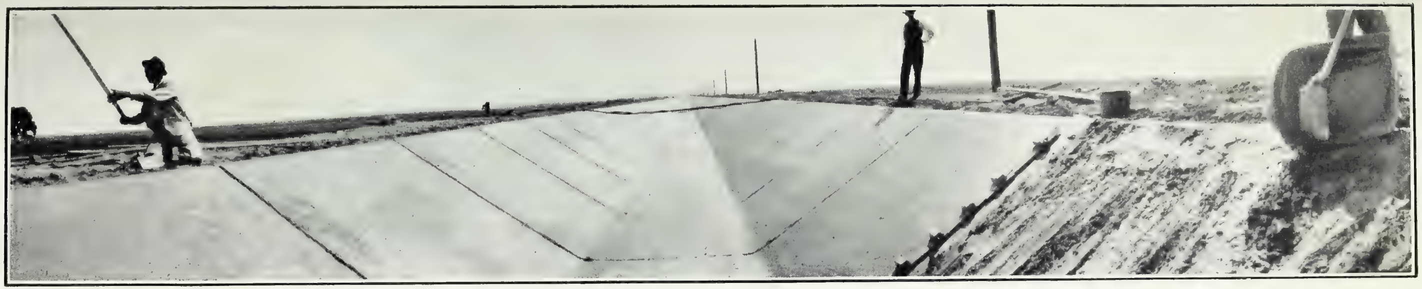

FIG. 1.—PORTION OF LINED CANAL, PATTERSON LAND & WATER CO., PATTERSON, CAL.

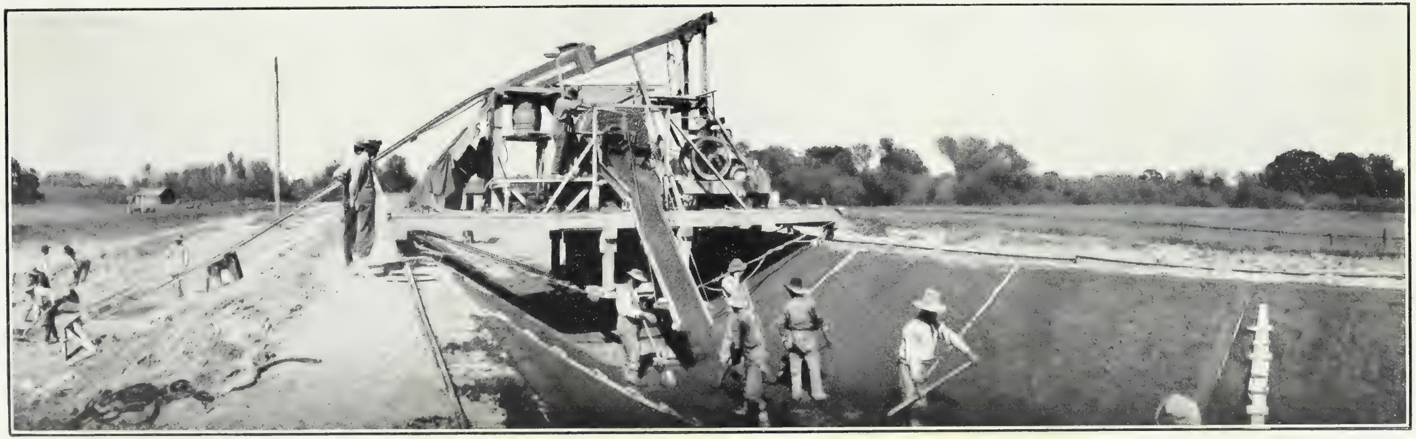

FIG. 2.—CONSTRUCTING CONCRETE LINING IN MAIN CANAL, PATTERSON LAND & WATER CO., PATTERSON, CAL.

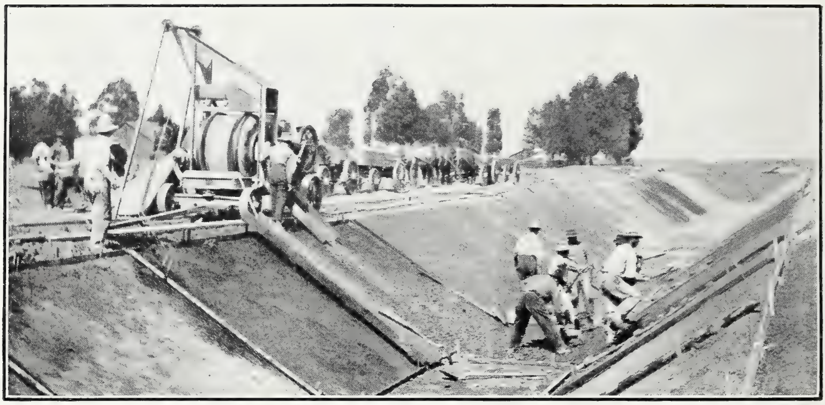

FIG. 1.—LAYING CONCRETE LINING IN CANAL OF EAST CONTRA COSTA IRRIGATION PROJECT, BRENTWOOD, CAL.

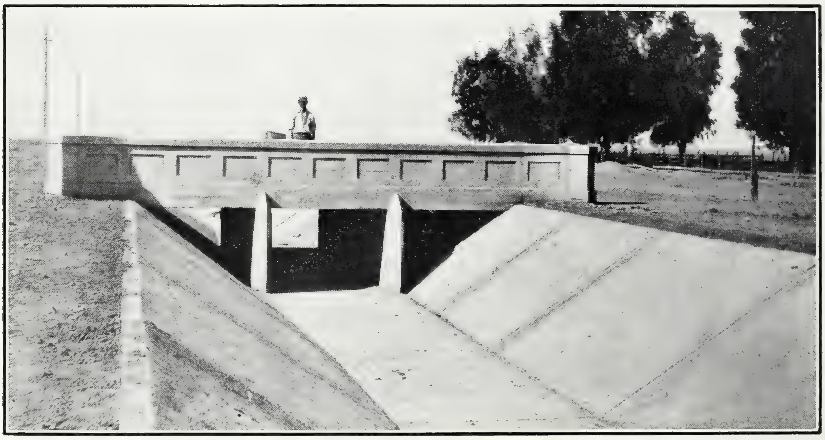

FIG. 2.—CONCRETE-LINED CANAL OF THE EAST CONTRA COSTA IRRIGATION PROJECT, BRENTWOOD, CAL.

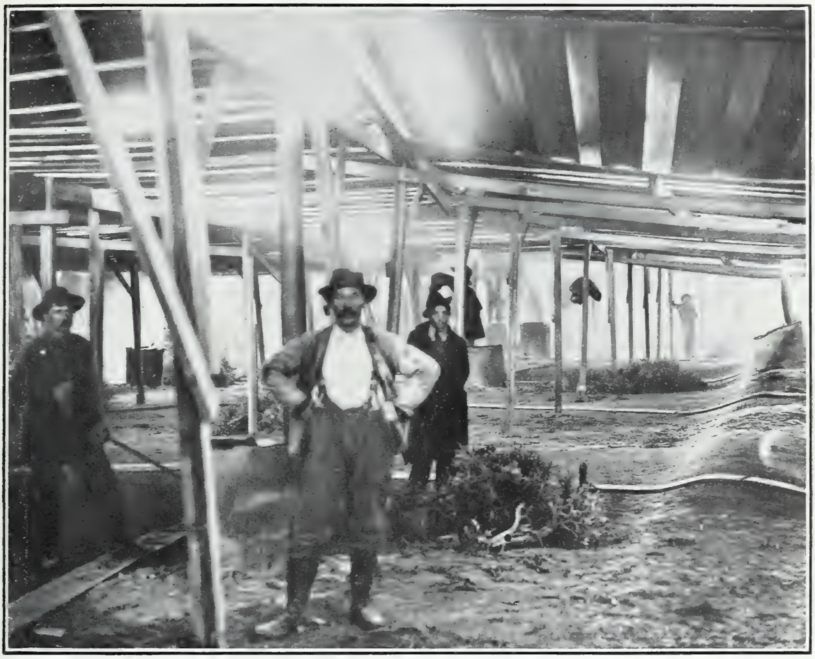

FIG. 1.—COVERING USED FOR CANAL AND METHOD OF HEATING WHEN CONCRETE LINING WAS BEING CONSTRUCTED, NORTH SIDE TWIN FALLS LAND & WATER CO., MILNER, IDAHO.

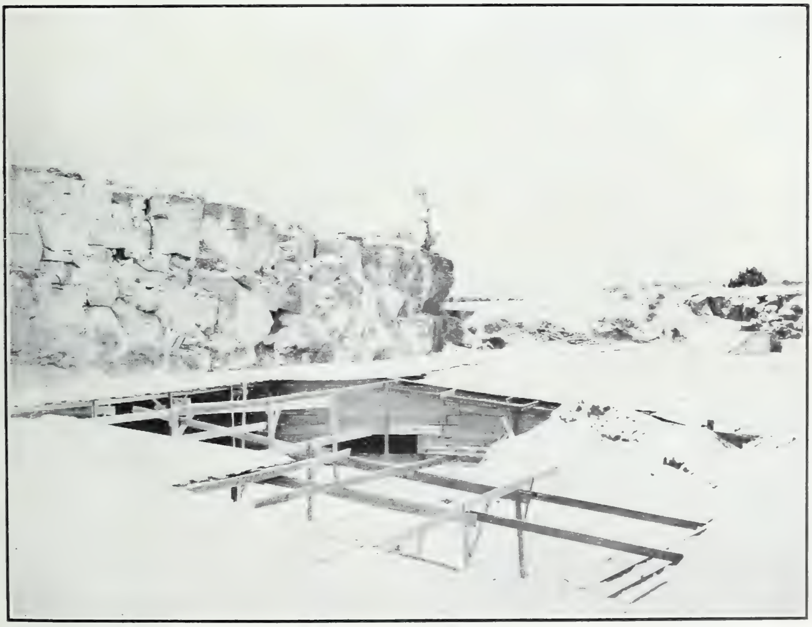

FIG. 2.—OUTSIDE VIEW OF COVERING USED FOR CANAL WHEN CONCRETE LINING WAS BEING CONSTRUCTED, NORTH SIDE TWIN FALLS LAND & WATER CO., MILNER, IDAHO.

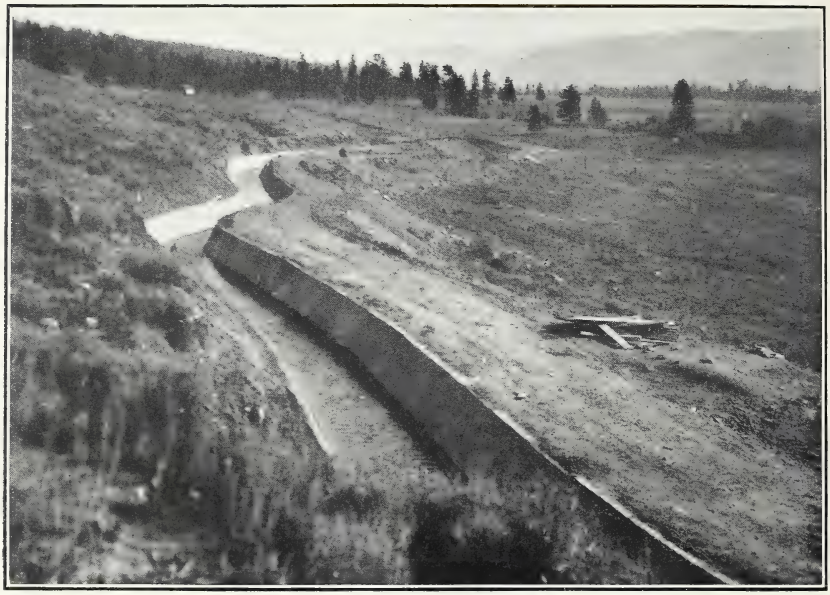

FIG. 1.—CONCRETE-LINED CANAL FOLLOWING THE LOCATION OF AN OLD CHANNEL, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

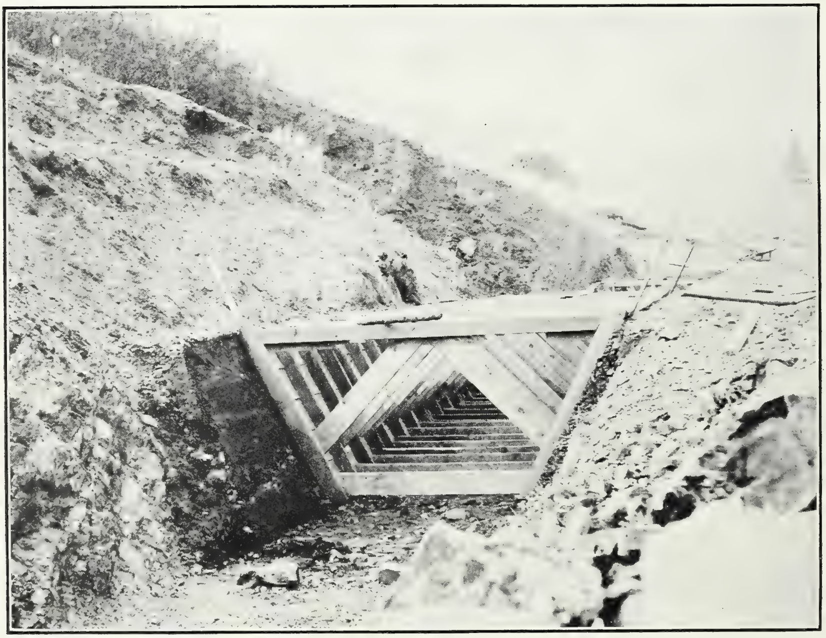

FIG. 2.—FORMS USED FOR BACKFILLING WITH PUDDLED EARTH TO PREPARE CANAL FOR CONCRETE LINING, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

between the forms was smoothed and thoroughly hand compacted. A uniform layer of concrete 4 inches thick was then applied.

After heavy stripping, a good natural mixture of sand and gravel was secured adjacent to the canal. This was hauled by slip scrapers up a runway and dumped into the mixers, which were placed high enough to permit discharging the concrete directly into one-horse carts. The concrete was a 1:3:6 mixture of Portland cement, sand, and gravel. It was laid in sections measuring 8 by 16 feet on the slopes and 8 by 16 or 16 by 16 feet on the bottom. The lining was laid in alternate sections to make room for the workmen, and the upper sections were usually the first completed. As soon as the concrete of the first sections had set, the forms were removed and the intermediate sections filled in. Expansion joints of one thickness of tar paper were used between sections in part of the work.

After being dumped from the carts, the concrete was worked down and later smoothed by drawing long floats made of 2 by 6 inch timbers back and forth across the forms. In order to get a smooth face, the surface was painted with a 1 to 2 finishing coat of cement mortar as soon as the concrete was placed and set. The lining was kept wet by sprinkling for a period of seven days after being laid. It was protected from nightly freezes during the early part of the work by covering with a layer of straw, and during some freezing weather in the latter part of the work some concrete was laid under large tents heated by stoves.

Some of the cost items are as follows:

Cost of lining New York Canal.

Preparing canal section for lining, per linear foot, approximately	$2.80
Hauling gravel to mixers, per cubic yard	1.14
Mixing and placing concrete, per cubic yard	2.20
Total cost of concrete, including cement, per cubic yard	7.70
Total cost of concrete in place, per lineal foot	9.64
Cement per barrel, f. o. b. Boise	$2.27–2.50
Common labor, per day	2.50
Man and team, per day	5.00

FRUITLAND IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

This company has lined some 6 miles of its main canal. The writer examined the lined portion of this canal in the summer of 1912 and found it in good condition. The upper bank is quite generally in excavation and the lower bank is partly in excavation and partly in fill. There appear to be more curves than the nature of the ground warrants, but A. E. Meighans, the company engineer, stated that the lined canal follows an old location for a ditch built before this company acquired the property. (Pl. V, fig. 1.)

Some slight injury to the lining has resulted from earth settlement. Lining the sides of the curves required the use of short forms, which were also used on tangents, resulting in a much larger number of joints on the straight portions than good practice warrants. The joints were spaced 6 feet apart, and an attempt has been made to cover the seams with a coating of cement mortar. It is claimed, however, that these will eventually become filled with sediment, but the daily and seasonal contraction and expansion usually tend to enlarge rather than to decrease their width.

Plate V, figure 2, shows the forms used for back-filling with puddled earth to prepare this canal for concrete lining. In Plate VI, figures 1 and 2, these forms have been removed and the channel is ready to receive the forms used in placing the concrete, as shown in Plate V, figure 2. Additional information on construction methods used with other useful data are to be found elsewhere.[1]

NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

During the winter of 1910–11 this company lined 22,500 feet of ditches on the "Highlands" at Kennewick to eliminate heavy seepage losses. The soil through which these ditches are built is principally a fine sandy loam overlying gravel at a depth of 18 inches to 2 feet.

One ditch 10,800 feet long, 3 feet wide on the bottom, with side slopes of ½ to 1 and a vertical depth of 26 inches, is designed to carry 18 second-feet. Another ditch having in part a bottom width of 3½ feet, side slopes of ½ to 1, and a vertical depth of 19½ inches is designed to carry 14 second-feet. This ditch is reduced to a bottom width of 2½ feet, but with the same side slopes and depth as the upper part. The concrete used was a 1:3:4 mixture of cement, sand, and crushed rock.

In preparation for lining, center grade stakes were set and the bottom of the ditch brought to grade. Scantlings 2 by 4 inches were then placed across the bottom of the ditch at 12-foot intervals at right angles to the center line and flush with the subgrade. Three forms 12 feet long (Pl. VII, fig. 1) were then set in the ditch on the cross strips and centered. Earth was shoveled and tamped behind the forms to secure the desired section. There were 14 men in a crew on this work.

After the earth sections were prepared in this way, 2 by 2 inch screeds (Pl. VII, fig. 2) were placed at intervals of 5 feet 8 inches and upon them forms 6 feet long were set on every other space. The concrete was mixed with a one-third yard mixer, wheeled to place and dumped on planks laid on top of the forms. It was then shoveled behind the forms and lightly tamped. Strips of sheet iron were inserted behind the forms to protect the slope while the concrete was being put in and also to prevent a too rapid loss of water from the mixture by its contact with the drier earth. These strips were raised as the filling progressed. Two crews of 5 men each placed the concrete behind the forms, 2 men wheeled to each crew, and about 5 men were employed to move forms, etc. About 6 men were in the mixing crew and 2 others plastered rough places in the lining.

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[1] Brit. Columbia Dept. Agr. Bul. 44 (1912).

Water kept in the finished ditch a few hundred feet in the rear of the work (Pl. VII, fig. 3), was pumped ahead to the mixer with a small gasoline engine.

The engineer stated that in one hour a crew could place about six sections, or 34 lineal feet, of the lining in the ditch having a 3-foot bottom.

On some of this work done during freezing weather, canvas covers were placed over the ditch. Under these covers iron pipes were laid through which steam was run from a steam boiler during the night.

Rock gathered from various places within the locality was crushed and hauled from 1 to 1½ miles. Six men collected the rock, 4 men operated the crusher, and about 7 teams hauled the crushed rock to the place of use. The cost of the crushed rock was not obtainable, but other items of expense were as follows:

Cost of labor and materials for lining Northern Pacific Canal.

Cement per barrel delivered at works, approximately	$3.00
Sand delivered by contract, per cubic yard	1.75
Laborers per hour, without board	.25
Teams per hour, without feed	.35

TRUCKEE-CARSON PROJECT, NEVADA.

A part of the main lower Truckee Canal constructed in 1904 and 1905 by the United States Reclamation Service was lined with concrete. Much of this lining was placed without the use of expansion and contraction joints. In November, 1911, about six years after the lining was completed, Mr. F. L. Peterson, irrigation engineer of this office, made a careful examination of the lined portions of this canal to determine if possible the effect produced by the lack of joints. Plate VIII, figure 1, is a general view of the lined canal opposite the railroad siding at Gilpin, Nev. Here the canal is excavated for the most part in solid rock and lined with 4 inches of concrete. In the same plate are shown fractures in the lining after a thin mortar coating had been placed over the seams. Plate VIII, figures 2 and 3, gives a closer view of two of the fractures, the latter one of which has been repaired.

The general specifications for the concrete used on this work provided:

> The concrete to be used on all the structures and tunnels on this canal will be composed of Portland cement, sand, and gravel or broken stone, in the proportion of

1 barrel of cement to 7 full barrels of the same size of aggregates when mixed together. If broken stone is used, it must be hard, clean, and heavy, having at least a specific gravity of 2 and screened into three different sizes. None of the gravel is to exceed 2 inches in diameter. The mixture of such sizes will be in the proportion determined by the engineer. All of the rock must be of such size that it will pass through a screen with a 2-inch square mesh.

The seam shown in Plate IX, figure 1, is typical of many such seen in canal lining in that it gradually diminishes in width from the top to the bottom of the side lining. Plate IX, figure 2, shows a fracture extending not only through the concrete but also through a diabase rock some 14 inches long and 4 to 6 inches thick which was embedded in the concrete. The natural cleavage of this rock, it may be observed, was nearly at right angles to the rupture as made by the contraction of the concrete.

The placing of the concrete lining against the uneven rock surface served to anchor the lining and prevent contraction, and this same foundation condition doubtless added much to the strength of the lining as a whole. Notwithstanding this fact, however, ruptures have occurred at intervals of 28 feet or more throughout the lining. The seams created by these ruptures varied in width from one-twelfth to one-half inch or more at a time when the temperature of the air was 50° and that of the water in the canal was 42° F.

LOWER YAKIMA IRRIGATION CO., RICHLAND, WASH.

The canal of this company parallels the Yakima River for several miles, where the earth sections run mainly through coarse gravel, bowlders, or shattered basaltic rock. The remainder of the system is very largely built through sand. In the unlined channel the seepage losses were excessive, and through the sand it was also difficult to maintain the ditch owing to its tendency to fill up both by drifting and on account of the flat side slopes which the sand naturally assumed under the action of water. The lining was intended, therefore, not only to reduce the loss of water but to increase the carrying capacity of the ditch and render it more stable and easy to maintain. About 5 miles of the ditch was lined in 1910. The company furnished all materials used and prepared the channel for lining, but the other work was done by contract.

In preparing the ditch, center stakes were set about 1½ inches above grade, to which the excavating was roughly done with teams and scrapers. At intervals of about 25 feet along the bottom of the side slopes stakes were set to grade, and from these the top slope stakes were set by the use of a slope triangle. Nails were driven into the grade stakes and chalk lines were stretched on them parallel to the ditch. Trimming to these lines was done then with square-pointed shovels and the slopes and bottom scraped to smooth sur-

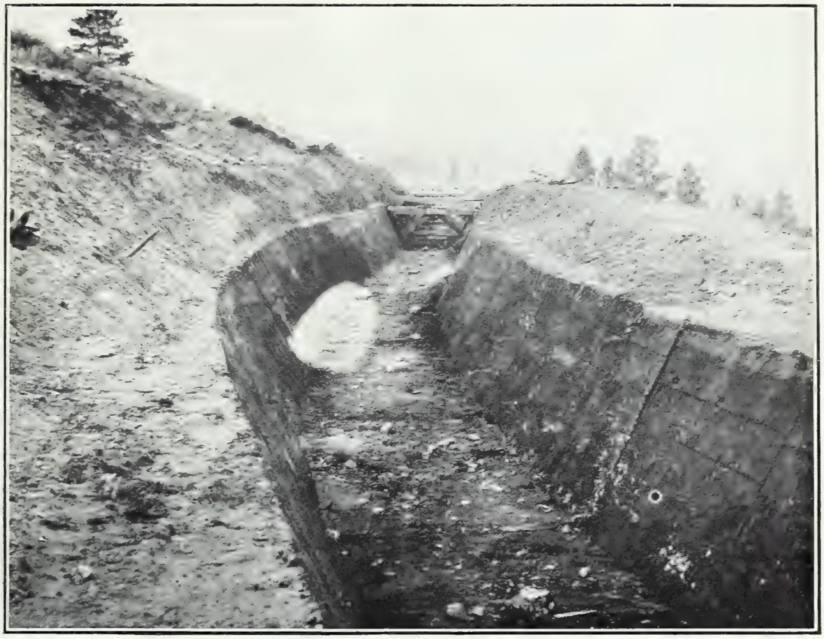

FIG. 1.—EARTHEN CANAL PREPARED FOR CONCRETE LINING, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

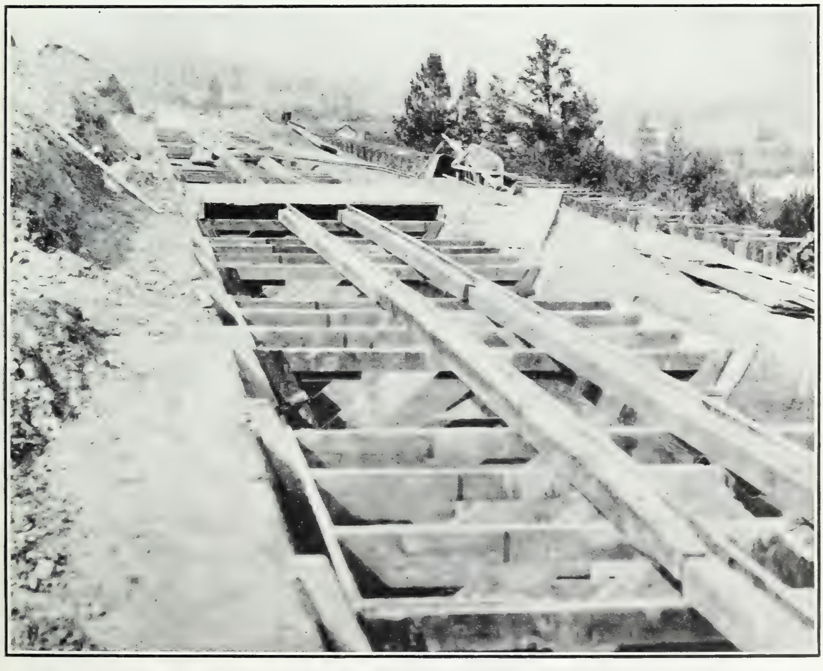

FIG. 2.—FORMS PLACED TO RECEIVE CONCRETE, FRUITLANDS IRRIGATION & POWER CO. (LTD.), KAMLOOPS, BRITISH COLUMBIA.

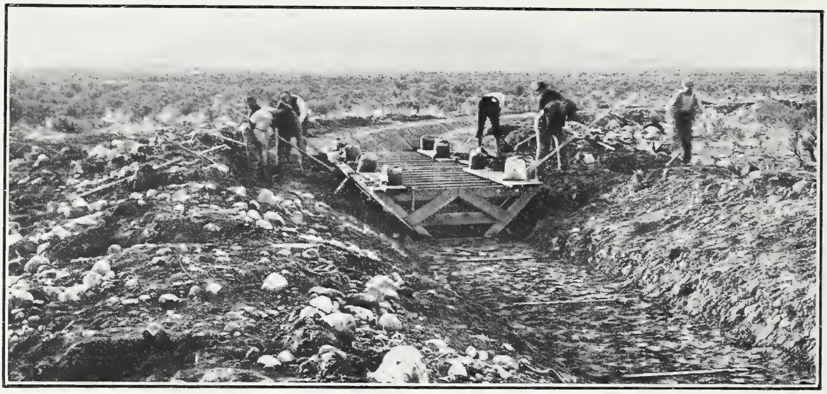

FIG. 1.—PREPARING EARTHEN CANAL SECTIONS FOR CONCRETE LINING, NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

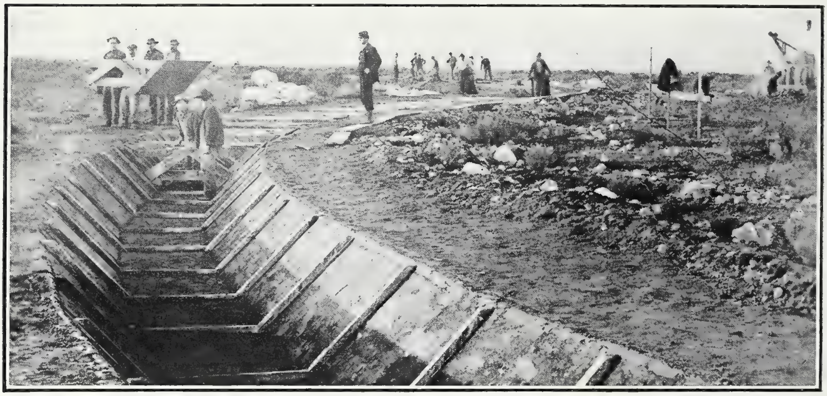

FIG. 2.—SETTING FORMS PREPARATORY TO CONSTRUCTION OF CONCRETE LINING, NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

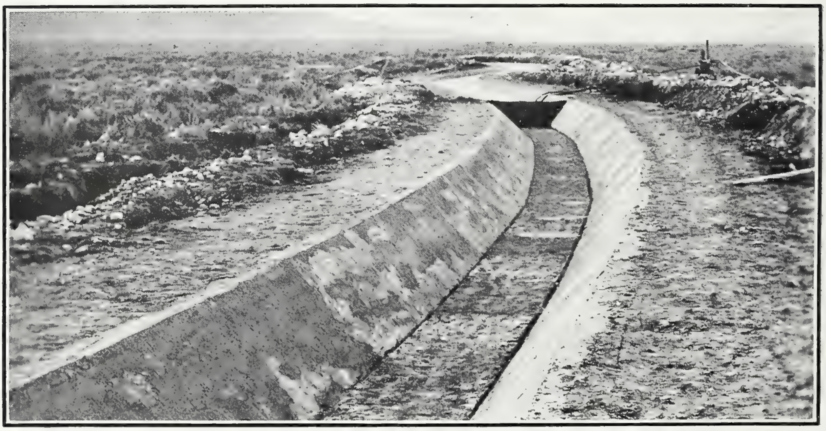

FIG. 3.—SECTION OF CONCRETE-LINED CANAL, NORTHERN PACIFIC IRRIGATION CO., KENNEWICK, WASH.

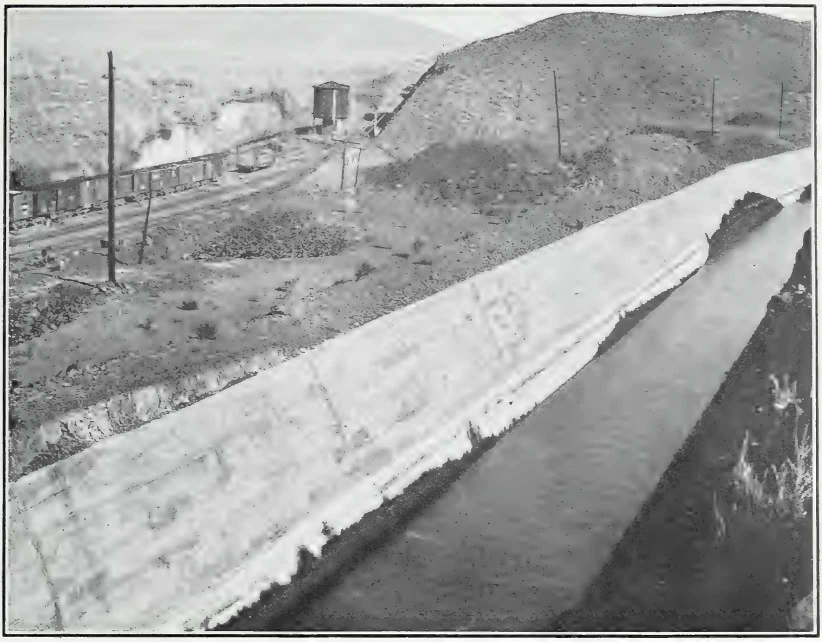

FIG. 1.—CONCRETE LINING IN TRUCKEE-CARSON CANAL, AT GILPIN, NEV.

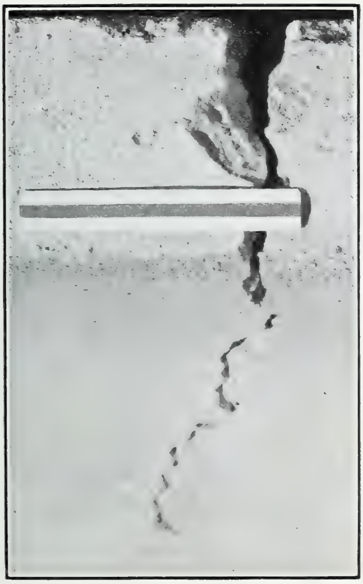

FIG. 2.—SHOWING FRACTURES IN CONCRETE LINING OF TRUCKEE-CARSON CANAL, NEV.

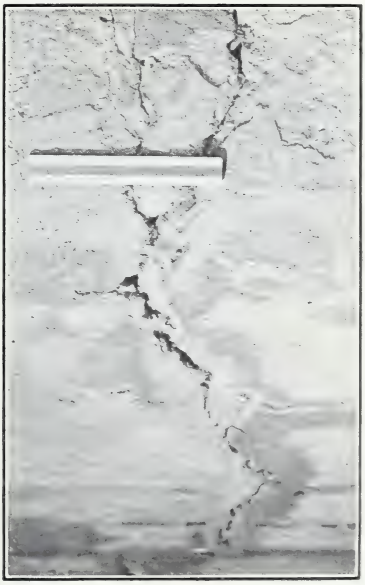

FIG. 3.—SHOWING FRACTURES IN CONCRETE LINING OF TRUCKEE-CARSON CANAL, NEV.

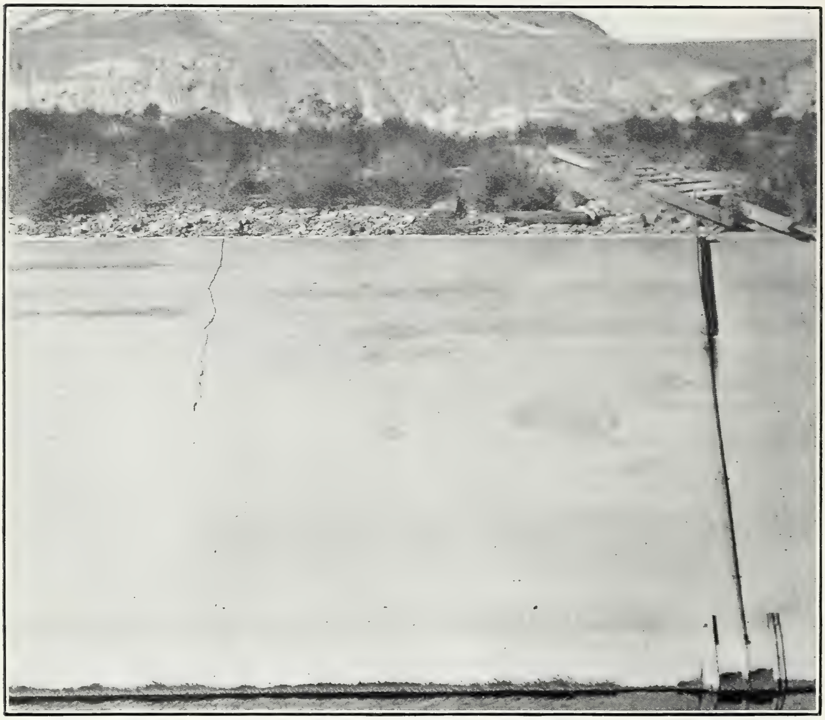

FIG. 1.—TYPICAL CRACK IN CONCRETE LINING, TRUCKEE-CARSON CANAL, NEV.

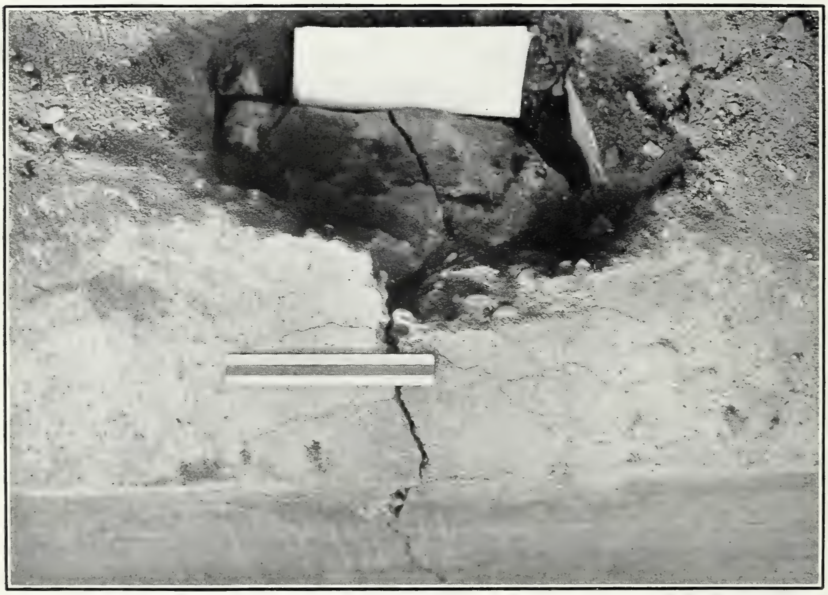

FIG. 2.—CRACK IN CONCRETE LINING EXTENDING THROUGH DIABASE ROCK, TRUCKEE-CARSON CANAL, NEV.

faces with straight-edges. The sides and bottom were tamped lightly with wooden tampers and sprinkled before the lining was applied. The section lined has a bottom width of 11½ feet, side slopes of 1½ to 1, and a wetted perimeter of 26½ feet.

The three mixers used were operated on planks in the bottom of the ditch in advance of the work. With each mixer there was a crew of about 25 men and in addition a finishing crew of 5 or 6 men to dress the earth surfaces immediately ahead of the mixer. One rock crusher was also operated, the crushed rock being hauled an average of 2 miles. Most of the sand was procured from pits along the line of the canal and was used without screening. The lining was laid in 8-foot sections 1¾ inches thick, with strips of building paper in the joints between the sections. Four hundred feet of lining was considered a good day's work for a crew.

A 1:3:4 mixture of concrete was used for most of the lining, but on one section a 1:4 mortar applied 1 inch thick was considered just as good as the thicker lining of concrete, besides being much easier to apply.

The lining in gravel sections leaked considerably the first season, presumably because allowed to dry too rapidly on account of lack of water for keeping it moist after laying. In work that was done the following year this difficulty was obviated by allowing a small amount of water to flow in the ditch soon after lining, using check dams to prevent its interference with construction. Men wearing rubber boots then waded along and with shovels or buckets threw water upon the side slopes at frequent intervals to keep the concrete wet while setting. Where lining had been placed on moistened sand, the results were better than in the sections through gravel, there being no perceptible leakage. Conditions in the gravel portion improved with the first year's use of the lined section, after which the seepage was considerably lessened.

The various items of cost secured are as follows:

Cost of lining canal of Lower Yakima Irrigation Co.

Laborers per day of 10 hours, without board	$2. 50
Man and team per day, without board	4. 50
Contract price per square foot for mixing and laying concrete	. 025
Cement per barrel [1]	3. 10
Sand per cubic yard, approximately	. 50
Total cost of lining, per square foot	. 065
Total cost of lining	9, 064. 49

During February and March, 1911, the company placed additional lining, using practically the same methods above described, except that all work was done by force account. The prices for labor and material indicate that the work was done considerably cheaper than in the previous year. Laborers were procured for $2 per day without board and men with teams for $4 per day each. Cement cost $2.95 per barrel delivered at the work.

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[1] This does not include an 8-mile haul over heavy roads.

BELGO-CANADIAN FRUIT LANDS, KELOWNA, BRITISH COLUMBIA.

About 3,000 feet of this company's main canal, 11 miles long, and about 4 miles of its lateral ditches have been recently lined with concrete to prevent seepage losses in a porous soil. On the main canal a 3-inch thickness of lining has been used for a finished section having a bottom width of 3.5 feet, depth 3.75 feet, and side slopes of ½ to 1. Lateral linings are 2½ to 3 inches thick on slopes, with a 3-inch thickness on bottoms which vary in width from 9 inches to 2 feet.

After excavating the channel to be lined, a drain filled with loose rock or gravel was made beneath the bed. Cross drains from this through the lower bank were placed at 500-foot intervals. The forms shown in figure 7 were then set and bolted together. Galvanized-iron plates placed outside the forms were spaced with pieces of lumber, and after the earth was back-filled and tamped behind the plates concrete was poured between them and the forms. The galvanized plates and spacing pieces were withdrawn as the space was filled with concrete. The bottom of the ditch was then floated in and the edges smoothed, using for this purpose the excess concrete which had passed over the forms. The forms were left in place 48 hours.

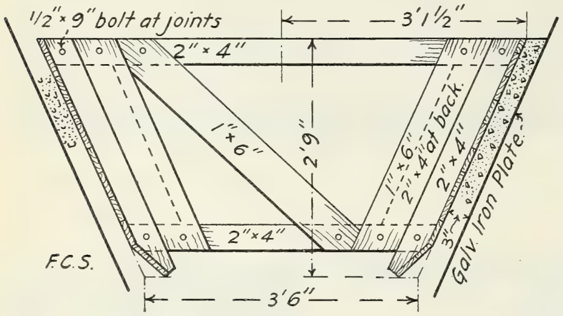


FIG. 7.—Section of form used for placing concrete lining, Belgo-Canadian fruit lands, Kelowna, British Columbia.

Curves were made by using special short forms having the outer edge superelevated ½ to 1 inch according to the degree of curvature. In placing the concrete around sharp curves, special galvanized plates were used to close the gap at the outer edge of the forms.

No cost data could be secured on the lining of the main canal. The cost of lining laterals per square foot and exclusive of excavation varied from $0.118 in the larger to $0.142 in the smaller ones. These costs include excavation, back-filling, rock drains, and supervision. The work was done late in the fall when protection against frost increased the cost. Cement cost $3.75 per barrel delivered, common labor $2.75 per day, and skilled labor $4 per day.

TUCSON FARMS CO., TUCSON, ARIZ.

The water for this project is obtained by pumping from numerous wells. During the winter and spring of 1912–13 a reinforced concrete lining was placed in about 2½ miles of the new main canal for the prevention of seepage losses through a sandy and gravelly soil.

The canal has a trapezoidal cross section entirely in excavation and as lined is capable of carrying a 2.9-foot depth of water. The bottom width ranges from 2 to 4¾ feet and the side slopes are 1 to 1. The greater part of the concrete used in this construction is a 1:4 :4 mixture and the lining is 3 inches thick throughout.

In grading the channel for lining, a framed template was used to get a true section. The reinforcement is made of round steel bars intersecting at right angles and wired together. Four longitudinal bars, $\frac{5}{16}$-inch diameter, were placed one on each side of the bottom for the lining floor and one on each side near the top of the side walls. Then at right angles to these, as stated, ¼-inch crossbars were spaced 12 inches apart. Each crossbar was continuous and extended from the top of the lining on one side through the lining to the top of it on the opposite side of the canal. When it was not possible to obtain the ¼-inch bars, $\frac{5}{16}$-inch bars were substituted and spaced 18 inches apart.

Wooden-framed forms built in 12-foot sections were then set in position over the steel reinforcement, blocked to place, and the adjoining ends bolted together. Then ⅛-inch steel backing plates, 2 feet wide and long enough to reach to the bottom of the earth section, were slipped behind the forms and under the reinforcement. Before placing the concrete, wooden spreader-strips 2 by 3 inches were set between the wooden forms and the backing plates. Each spreader contained a staple driven almost full length into its side near the bottom, and in setting the spreader the staple loop was slipped over the end of the crossbar and the spreader was then slid into position. In this way the bar was carefully held in position while the concrete was being placed in the forms. A spreader was set beside each crossbar, and as the concrete for the side lining was tamped and puddled into place the spreaders were gradually removed, leaving the crossbars firmly embedded in the concrete. The steel plates likewise were withdrawn as the walls were built up. When the side forms were filled with concrete to within 3 inches of the top, the longitudinal bars were placed and wired to the crossbars. The remaining concrete was then placed and smoothed with an edging trowel.

Expansion joints were provided by setting 1 by 3 inch wooden strips in the middle of each form in the same manner as the spreaders, except that no staples were used and the joint strips were not removed afterwards. To keep them in position while concrete was being deposited, each one was lightly nailed to the side of the form, and before the latter was removed the nails were withdrawn.

The forms were left intact for a period of 8 hours at least, and they usually remained undisturbed over night during a period of 14 to 20 hours. After their removal any defects in the wall surface were "picked" out and the cavities smoothly plastered with a 1:1½ or 2 cement mortar.

The canal bottom was then carefully cleared of litter, its surface smoothed, and solidly tamped. All reinforcement bars that may have become bent were straightened. The bottom piece of the expansion joint was fitted to the two side pieces and its top carefully laid to grade. (Pl. X, fig. 1.) The concrete for the floor lining was then tamped and puddled into place, and when it had reached the required thickness the surface was easily brought to grade and smoothed by the use of a straightedge resting on the bottom joint strips as guides.

The entire lining was kept wet by continual sprinkling during a period of three to five days. After this was discontinued a wash coat of neat cement mortar was applied to the surface with a brush. (Pl. X, fig. 2.)

A 1:4:4 mixture of concrete was used on all the work except for about 1,000 feet of bottom where there was excessive external water pressure. In this portion of the canal a 1:3.2:3.2 mixture was used. As a further protection in one very wet and miry place, additional reinforcement was used in the bottom. Extending over a length of about 5,000 feet of the largest canal section near the Santa Cruz River bed, "weep holes" were formed in the bottom to relieve external water pressure. Two-inch tapering plugs extending entirely through the lining floor were set in the freshly laid concrete and these plugs were later removed as soon as the concrete had set sufficiently to retain its shape. Two rows of these holes were made 2½ feet apart and spaced 4 feet longitudinally. During construction a considerable portion of the canal was drained. A line of 8-inch tiling was laid in the bottom and pumps attached thereto were installed at intervals of about 1,000 feet to withdraw the accumulated water.

The contractor received $12.50 per cubic yard for the finished concrete lining, using slab measurement. This included all costs except the original purchase price of the steel reinforcement. However, no excavation was included and the company paid extra for the wash coat. The contractor rented a rock crusher and delivered the rock. Sand was obtained from the river bed.

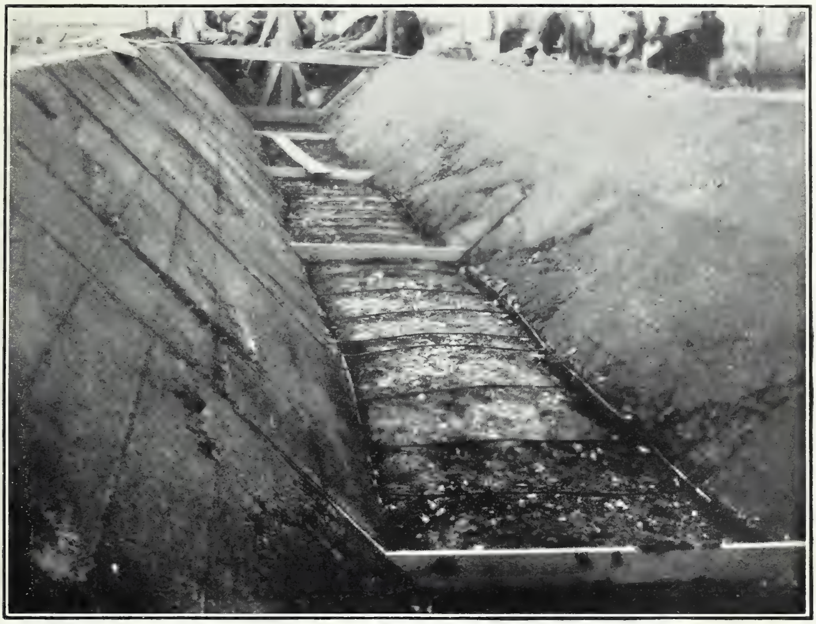


FIG. 1.—CONSTRUCTION REINFORCEMENT AND EXPANSION JOINT STRIPS USED IN CONCRETE LINING WORK, TUCSON FARMS CO., TUCSON, ARIZ.

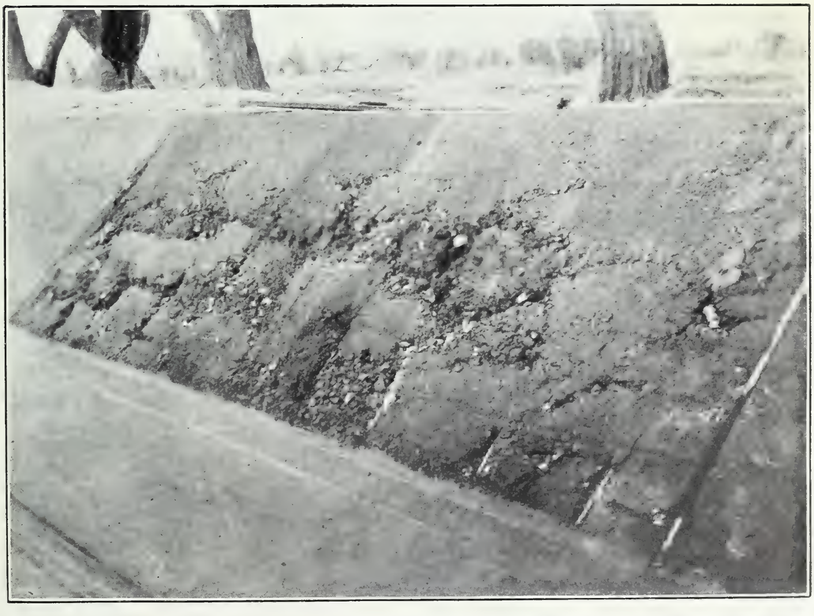


FIG. 2.—SHOWING EXPANSION JOINT STRIPS EMBEDDED IN CONCRETE LINING AND APPEARANCE OF CONCRETE SURFACE BEFORE APPLYING WASH COAT OF NEAT CEMENT MORTAR, TUCSON FARMS CO., TUCSON, ARIZ.

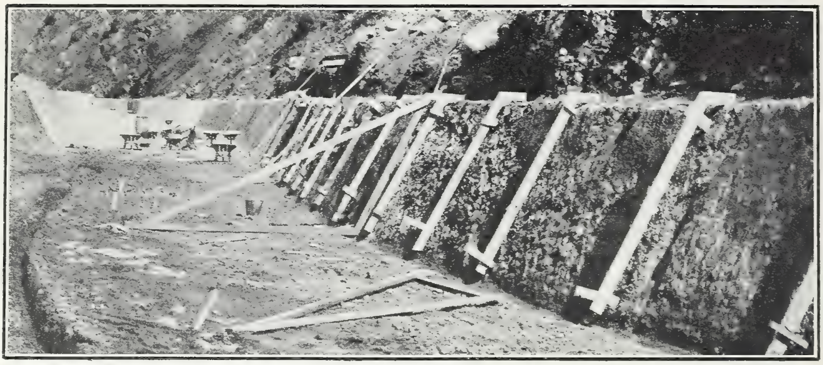


FIG. 1.—METHODS USED IN CONSTRUCTION OF CONCRETE LINING, DAVIS AND WEBER COUNTIES CANAL, OGDEN, UTAH.

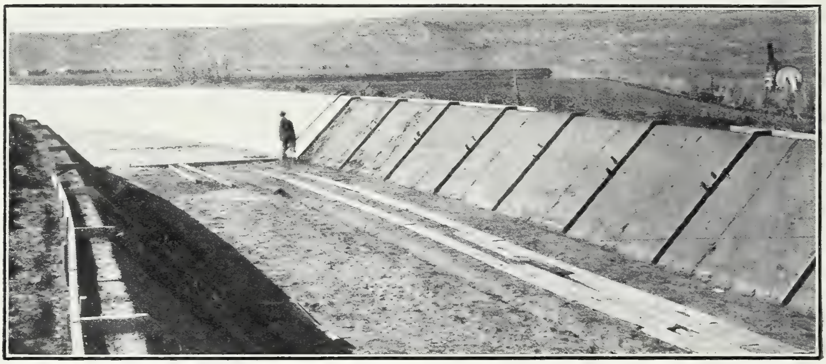


FIG. 2.—METHODS USED IN CONSTRUCTION OF CONCRETE LINING, DAVIS AND WEBER COUNTIES CANAL, OGDEN, UTAH.

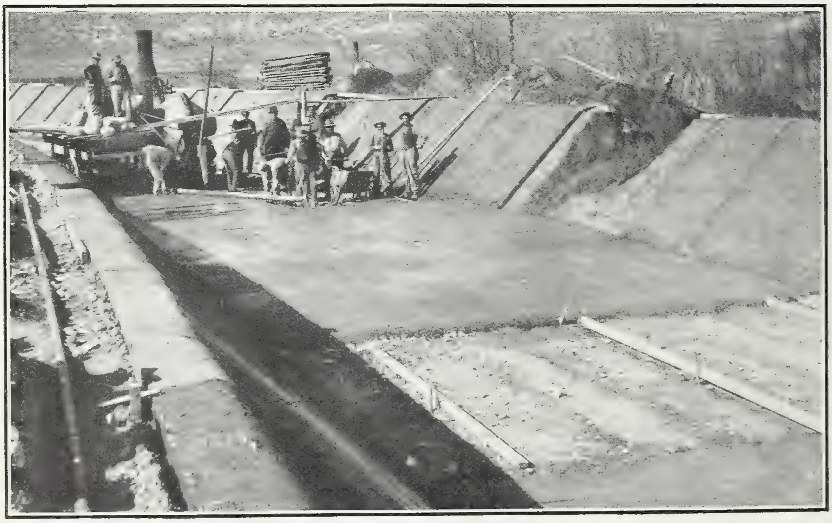


FIG. 3.—METHODS USED IN CONSTRUCTION OF CONCRETE LINING, DAVIS AND WEBER COUNTIES CANAL, OGDEN, UTAH.

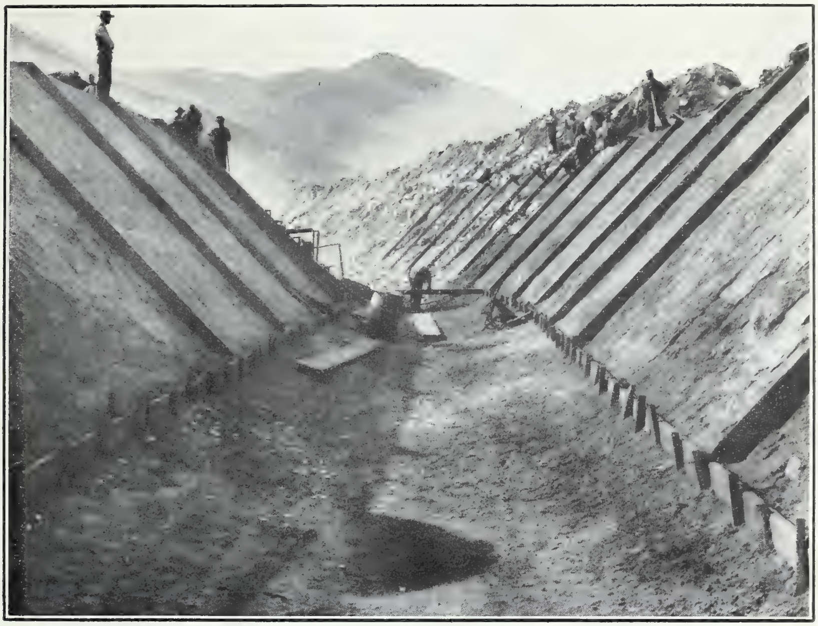


FIG. 1.—SETTING FORMS PREPARATORY TO PLACING CONCRETE FOR LINING OPEN CHANNEL, LOS ANGELES AQUEDUCT, LOS ANGELES, CAL.

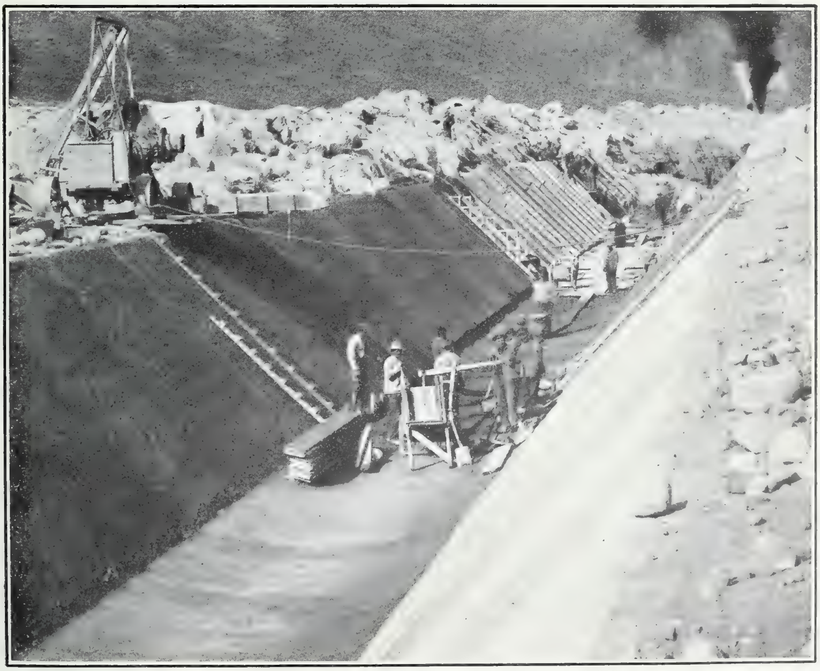
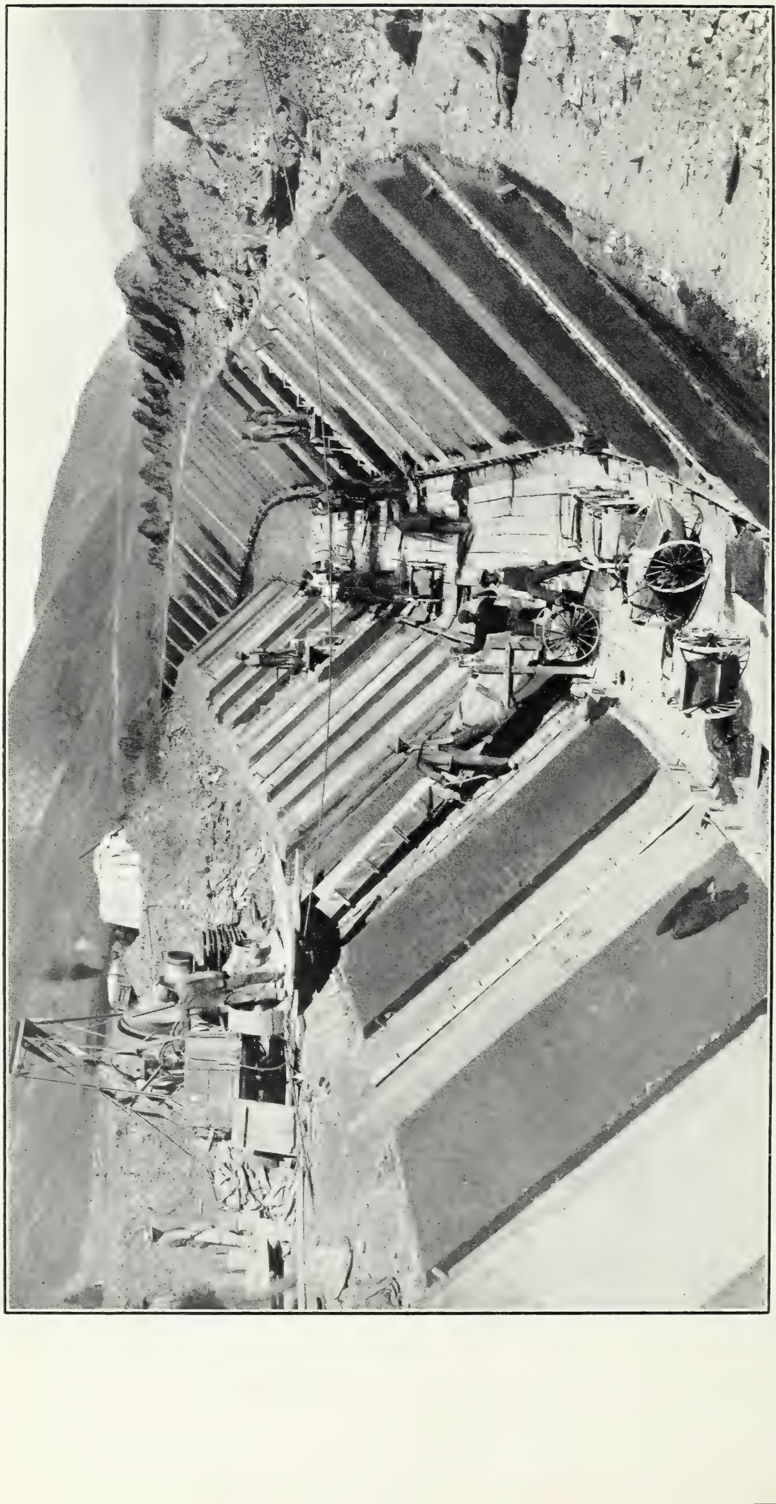


FIG. 2.—CONSTRUCTION OF CONCRETE LINING IN PROGRESS, LOS ANGELES AQUEDUCT.



METHODS USED IN CONSTRUCTION OF CONCRETE LINING FOR OPEN CHANNEL, LOS ANGELES AQUEDUCT.

All concrete was mixed by hand and transported in wheelbarrows. The work was performed with gangs of about 30 men, paid for a 9-hour day, as follows:

Wages of labor lining canal of Tucson Farms Co.

1 foreman	$4.00
Mixing boss and 2 plasterers	2.50
2 water boys	1.00
25 men	2.00

The gang was used in the following manner: Eight men on mixing board, 2 tampers, 2 men pulling plates and spreaders, 2 men setting forms and putting in expansion joints, 2 men laying steel reinforcement, 14 men transporting and depositing materials and concrete, finishing, screening sand, etc. The forms were usually all moved at one time and the whole force engaged on that work.

It required this gang 21 days to place lining in 3,000 feet of canal in dry excavation having a bottom width of 3 feet. The cost to the contractor was distributed as follows:

Contractor's cost of lining canal of Tucson Farms Co.

Labor, including the building of forms	$1,297.83
1,712 sacks of cement, at $0.81 each	1,386.72
232 cubic yards of rock, at $1.75 per cubic yard	406.00
232 cubic yards of sand, at $0.75 per cubic yard	174.00
Lumber in 15 sections of 12-foot forms, 3,900 feet b. m., at $30 per M	117.00
Lumber for expansion joints, 750 feet b. m., at $30 per M	22.50
Lumber for spreaders, runways, etc., 750 feet b. m., at $30 per M	22.50
Water purchased from the city of Tucson, 21 days at $2	42.00
Hauling steel reinforcement	10.00
Depreciation of plant, breakage of tools, etc	20.00
Office expenses and expenses of contractor and superintendent, amounting to about $2 per day for this gang, 21 days	42.00
Total	3,540.55

Computations made on the above basis for 298.9 cubic yards, the cost was $11.845 per cubic yard. However, there were in addition the following costs to the Tucson Farms Co.:

Additional cost of lining canal of Tucson Farms Co.

9,300 pounds of steel, at $0.04	$372.00
One coat of cement wash, 34,500 square feet, at $0.0025	86.25
Engineering, about 5 per cent	195.00
Total	653.50

On this basis the actual cost of the completed lining was $14.03 per cubic yard.

CENTRAL OREGON IRRIGATION CO., DESCHUTES, OREG.

The north canal of this company is concrete lined and diverts water from the Deschutes River a short distance below Bend, Oreg.

A 1:4:5 mixture of Portland cement, sand, and crushed rock was used on this work, the extra amount of sand being required to replace a considerable portion of the grout lost in the dry wall back of the lining. In preparation for lining the earth slopes, made 1¼ to 1 to avoid the necessity for forms, were finished to within 4 inches of the inner surface of the completed work. The rock slopes, however, were so badly broken that it was necessary to fill cavities with hand-laid dry walls (fig. 8).

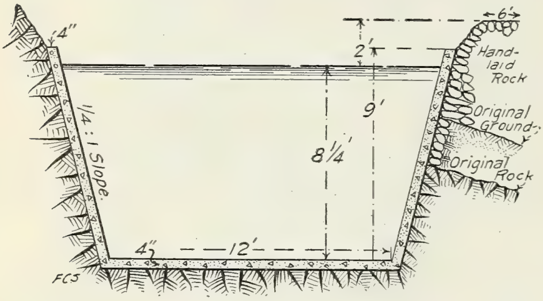


FIG. 8.—Section of concrete-lined canal in rock, Central Oregon Irrigation Co., Deschutes, Oreg.

Sectional forms made of shiplap were used repeatedly on the 6,300 lineal feet of canal through rock, but no forms were used on the 1,000 lineal feet of canal in earth. Expansion joints spaced at 12-foot intervals along the sides and bottom were made of ¼ by 4 inch wooden strips left in the finished concrete.

DAVIS & WEBER COUNTIES CANAL CO., OGDEN, UTAH.

During the years 1909 and 1910 this company enlarged and concrete lined 9½ miles of its main canal. When the canal was built in the eighties it carried less than 100 second-feet, but its capacity has been increased from time to time until in 1909 it reached 200 second-feet. It has been difficult and expensive to maintain this canal owing to its location near the top of a steep hillside flanking the Weber River on the south. In July, 1893, the writer made a series of current meter measurements to determine the seepage losses throughout its length. The results showed a discharge at the headgate in Weber Canyon of 105.5 second-feet which in 9½ miles seepage had reduced to 78½ second-feet, representing a loss of 26 per cent of the total diversion from the river. This seepage water found its way into the steep hillside and during 25 years of its operation as an unlined canal produced an endless variety of slides throughout a length of 7 miles. In fact, the whole hillside for this distance seemed to have been subjected to a severe earthquake shock. Tracts, several acres in extent, traversed by the canal have been known to drop through a vertical height of 7 feet as a result of the action of seepage waters on the underlying materials, and buildings located more than 600 feet from the center line of the canal have been removed from the path of the slides.

In the fall of 1909 the company undertook to enlarge and concrete line this canal and to provide for a maximum carrying capacity of 725 second-feet and at the same time retain the old location. This entailed the removal of a heavy growth of willows skirting the banks and a large amount of excavation. On account of the unstable character of the materials and the steep cross slope of the hill on which the canal is located the lining of so large a channel presented unusual difficulties. These have been met, however, and the canal successfully operated for the past two seasons.

The canal was provided with drainage at various stretches along its length through the use of 6-inch drain tiling laid in longitudinal trenches 10 to 20 inches deep. At intervals of about 800 feet these drains were connected to cross drains of the same construction to convey the drainage waters to the outside of the outer canal bank.

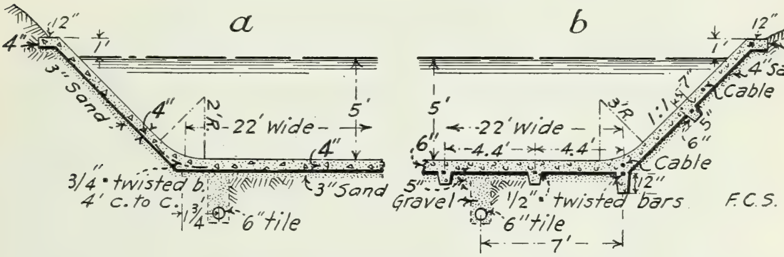


FIG. 9.—(*a*) General type of concrete lining construction used for Davis and Weber Counties Canal, Ogden, Utah. (*b*) Type of concrete lining used for weak foundations on the same canal.

It was at first proposed to use a 6-inch thickness of lining, but on the recommendation of the writer this was reduced to a 4-inch thickness for all but the worst portions. Figure 9, *a*, represents a cross section of 4-inch lining used for the greater portion of the channel. Where the canal bank was weak and where slides were liable to occur, a form as shown in figure 9, *b*, was adopted. In reducing the thickness from 6 to 4 inches a somewhat richer mixture was used and more precautions were taken to secure good drainage. The specifications for concrete called for a 1 : 2 : 4 Portland cement, sand, and gravel mixture, on which the contract price per cubic yard for concrete in place was $6.80, while for a 1 : 2½ : 5 mixture, also used, $6.45 was paid. On all straight portions of canal the concrete was laid in sections 20 feet wide. That placed on the bottom was first tamped into place and then carefully floated and smoothed. It was afterwards covered with sand kept moistened for a period of seven days by sprinkling. A 1 : 2 mortar of cement and sand was troweled over the surfaces of the slide slopes soon after the concrete had been tamped in and the forms removed. The slopes were then covered with burlap and kept moistened as described. The construction methods used on this canal are shown in Plate XI, figures 1, 2, and 3.

A tapering strip of wood, as shown in figure 3, *h*, forms the expansion and contraction joint between each section of concrete. The specifications called for the removal of these strips and the filling of the spaces with hot asphalt, but this was not done.

YAKIMA PROJECT, UNITED STATES RECLAMATION SERVICE, NORTH YAKIMA, WASH.

The Tieton main canal, located in the canyon division of this project, was provided for 10 miles of its length with concrete lining. Actual work commenced in 1907 and was finished in 1909. The steepness of the cross slopes, involving large excavation quantities per square foot of water area, and the lack of water-tightness in the material, made necessary an impervious canal and one that would withstand a high velocity. These requirements, together with a largely inaccessible locality having difficult working conditions, compelled the use of a minimum volume of lining, which it seemed advisable to make of molded concrete shapes cast in central yards. The cross section used for canals is shown in figure 10 and a portion of the constructed canal in figure 11.

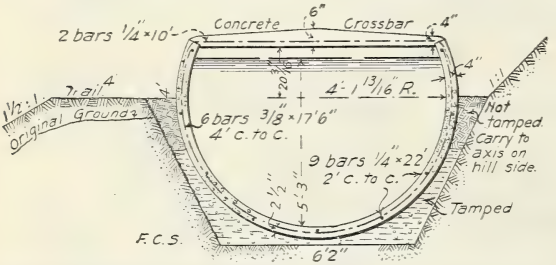


FIG. 10.—Cross section of open concrete-lined canal, Yakima project, U. S. Reclamation Service, North Yakima, Wash.

Curves of 57.6 feet radius were the maximum curvature used, and in some cases these were reversed with only a foot or two of tangent between. The canal was intended to have a carrying capacity of 300 second-feet.

The concrete aggregate was river gravel and sand and crushed gravel. The cost of manufacture of the lining per cubic yard was:

Cost of manufacture of lining for Tieton Canal.

Labor	$6.094
Material (cement and steel)	9.370
Plant charge	4.579
Engineering and inspection	.324
General	2.830
Total	23.197

The cost of placing and jointing a total of 49,494 lineal feet, including 23,295 shapes, raised the above cost to $32.05 per cubic yard, or $7.42 per lineal foot.

TURLOCK IRRIGATION DISTRICT, TURLOCK, CAL.

In 1910 this district made a hydraulic fill inclosing an old unsafe wooden flume on trestles across Peasley Gulch, and in the fall of that year, after the canal was emptied, the wooden flume box was removed and a concrete lining substituted. The lined section is 365 feet long, with a bottom width of 40 feet. The side walls, 4 inches thick and 9 feet high, are reinforced with No. 6 wire fabric (6 by 6 inches) and have a batter of $\frac{1}{5}$ to 1. Buttresses with the same batter are built at 8-foot intervals back of the lining and similarly reinforced. The floor, which is 6 inches thick and of the same construction as the sides, is concaved, being 1 foot lower at the middle than at the sides. Concrete floor ribs 12 inches deep and 8 inches wide are spaced equally with the buttresses and reinforced with two $\frac{1}{2}$-inch steel bars. The lining is made of 1:3:5 concrete placed behind wooden forms and cost $16 per cubic yard. It has no joints and no cracks of importance have developed.

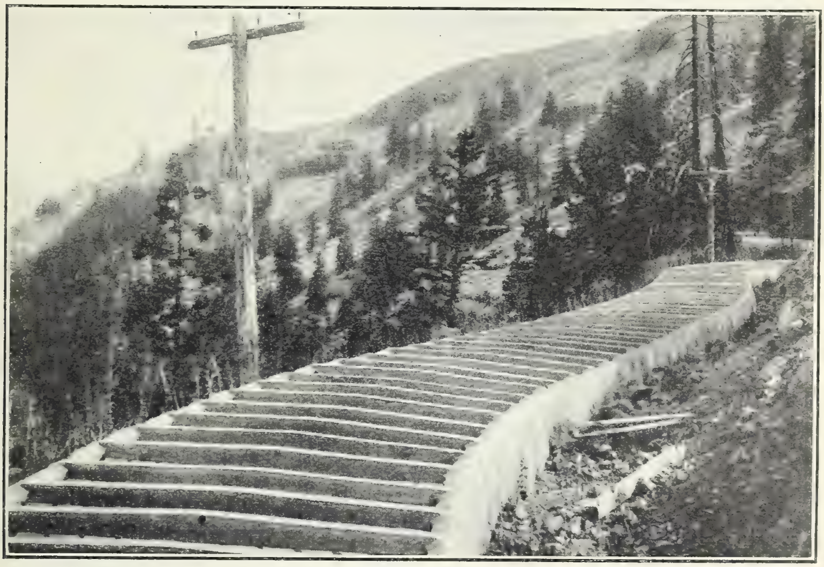


FIG. 11.—Concrete-lined canal, Yakima project, U. S. Reclamation Service, North Yakima, Wash.

MODESTO IRRIGATION DISTRICT, MODESTO, CAL.

Considerable concrete lining has been constructed to date in Modesto main canal, but all of it is for providing increased safety, and the small saving of seepage secured is merely incidental.

In the narrow canal sections near the headworks the velocities range from 5 to 8 feet per second. Where it has seemed necessary to provide considerable slab strength, the floor lining is from 4 to 6 inches thick. The linings for hydraulic fills recently completed are 6 inches thick and reinforced with No. 6 wire fabric 6 by 6 inches.

Linings of 2⅜ to 2½ inches thickness have been used on four stretches of lined canal having lengths of 250, 250, 575, and 1,000 feet, respectively. The bottom width is 44 feet and water depth of 5.5 for the first three and 34 feet and 7 feet, respectively, for the fourth. All slopes are 2 to 1. In preparation for the linings the canal sections were carefully graded and aligned by chalk line and straightedge. Fills were made a little high, with loose sand where possible, and after saturating with water were graded. Fills as high as 10 feet were graded and aligned within two or three days after the material was placed with a scraper, but they were made of clean sand thoroughly saturated with water. No settlement has been noticed. The lining was laid in cross strips 3 feet long longitudinally, and these were imperfectly bonded to permit cracking at the joints. The latter, being numerous, permitted only narrow cracks, which are unimportant. It is said that in part of this lining the water reaches a velocity as high as 20 feet per second at times and that no appreciable injury to the concrete has occurred after five or six years of use.

SOUTH SAN JOAQUIN IRRIGATION DISTRICT, MANTECA, CAL.

Concrete lining has been placed on 7 miles of the main canal, 3 miles of which is owned jointly with the Oakdale irrigation district. A typical lined channel has a bottom width of 11.36 feet, side slopes ¼ to 1, and is planned to carry a 9-foot depth of water and allow 2 feet additional for splash. This design, having a grade of 0.0775 per 100 feet, is intended to have a capacity of 850 second-feet. An excess grade for curves was computed from the following formula:

$$Hc=\frac{100\,v^3}{2gr^2},$$

where Hc is the excess grade in feet per 100 feet; v is the uniform velocity of water in feet per second; r is the radius of the curve in feet. The value of n for Kutter's formula was taken as 0.015. The lining thickness averages 4 inches for the bottom and 4 to 6 inches for the sides of the canal. A mixture of 1:3:6 concrete, placed behind forms and in alternate sections 12 to 16 feet long, was used without allowing expansion joints. In many places where the channel is in rock cut no back forms were used, and in such case the alignment is irregular and follows the contour of the side walls.

The cost of the concrete in the completed work was about $14.50 per cubic yard.

BURBANK POWER & WATER CO., BURBANK, WASH.

This company concrete-lined about 4,000 feet of canal in 1910. The essential features of the design are shown in figure 12 and the construction is reported to be giving satisfactory results.

The contract price of the concrete in place was $12.50 per cubic yard, and the engineering 7 per cent additional. The cement cost $2.75 per barrel at Burbank and $3.25 delivered at the work. Gravel and sand having within 5 per cent of the proportions used were found within a mile of the work and for which the contractor paid $1.75 per cubic yard delivered. The lining is made of a 1:2½:4½ mixture of concrete and is formed in cross strips 3 feet long.

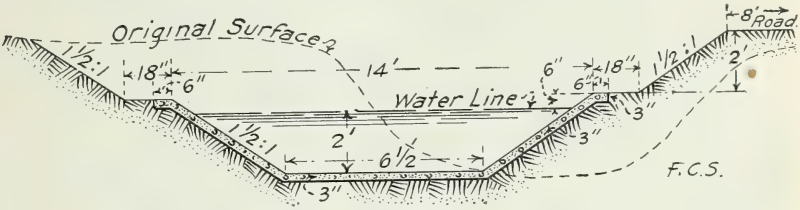


Fig. 12.—Cross section of concrete-lined canal, Burbank Power & Water Co., Burbank, Wash.

MEDINA VALLEY IRRIGATION CO., SAN ANTONIO, TEX.

Concrete lining has been placed in 2,390 feet of the main supply canal having in this portion of its length a capacity of 850 second-feet. The canal, located on a sidehill slope of 3 to 1, is excavated in limestone having some pockets of rotten limestone and adobe. The ground surface is covered with a layer of broken stone and débris.

The work of excavation and placing of the lining was let to contract. In order to keep a low excavation cost the contractor blasted heavily and for this reason needed a large amount of rubble backfill. Figures 13 and 14 show the main features of construction and the dimensions of the section used. Joints are spaced 16 feet apart, and while cracks have appeared no harmful results are anticipated.

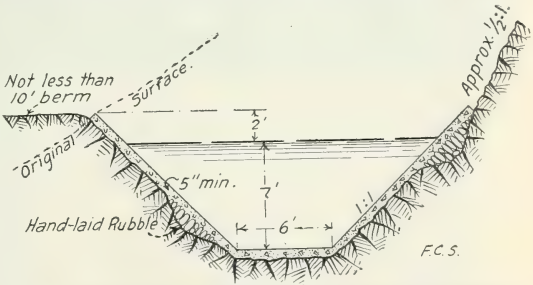


Fig. 13.—Cross section of concrete-lined canal, Medina Valley Irrigation Co., San Antonio, Tex.

Mexican labor, used on the work, cost $1.50 to $1.75 per day. The concrete was hand mixed, and except for the filling of local voids no plastering was done. The use of poor lumber for forms left an uneven concrete surface.

The contract prices were $0.90 per cubic yard for rock excavation, $6 per cubic yard for concrete in place, and $1.50 per cubic yard for dry laid rubble. The company paid for one-half the rubble needed for back filling the overbreakage. For the entire 2,390 feet of canal lined the costs per foot are:

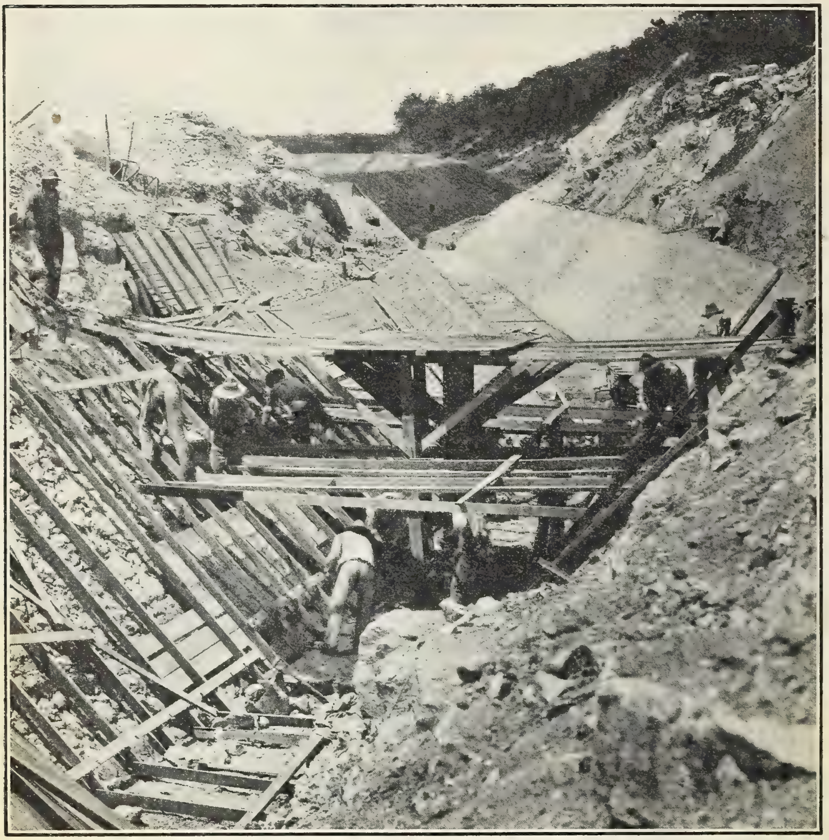
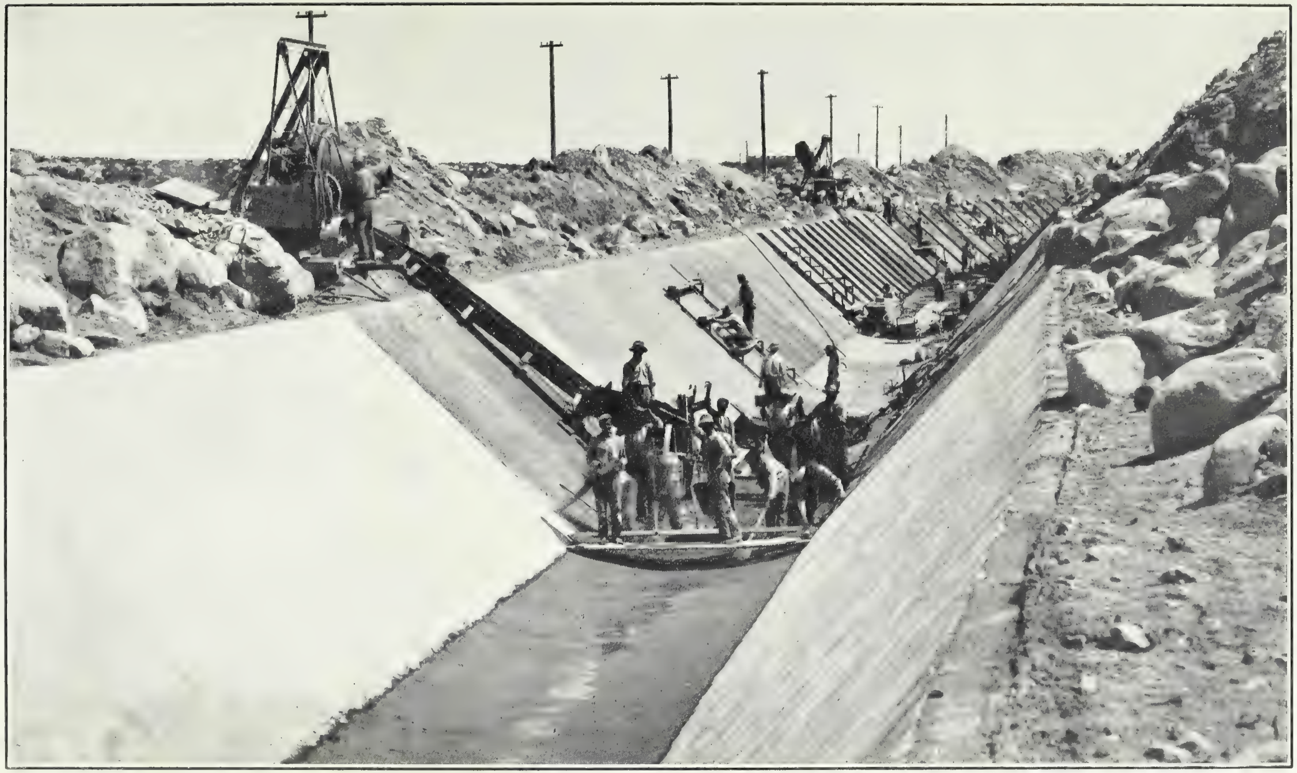


FIG. 14.—Construction methods used in placing concrete lining, Medina Valley Irrigation Co., San Antonio, Tex.

Contract prices and cost of lining Medina Canal.

	Approximate actual cost.	Cost to the company.
Excavation	$7.86	$10.56
Rubble	1.56	.86
Concrete	3.11	3.27
Cement	1.80	1.80
Total	14.33	16.49

Cement cost $2.40 per barrel delivered at a point on the railroad nearest the work. The cost of the concrete per square foot was 19 cents.



Portion of Completed Concrete-Lined Open Channel, Los Angeles Aqueduct. (Note the Curved Bottom.)

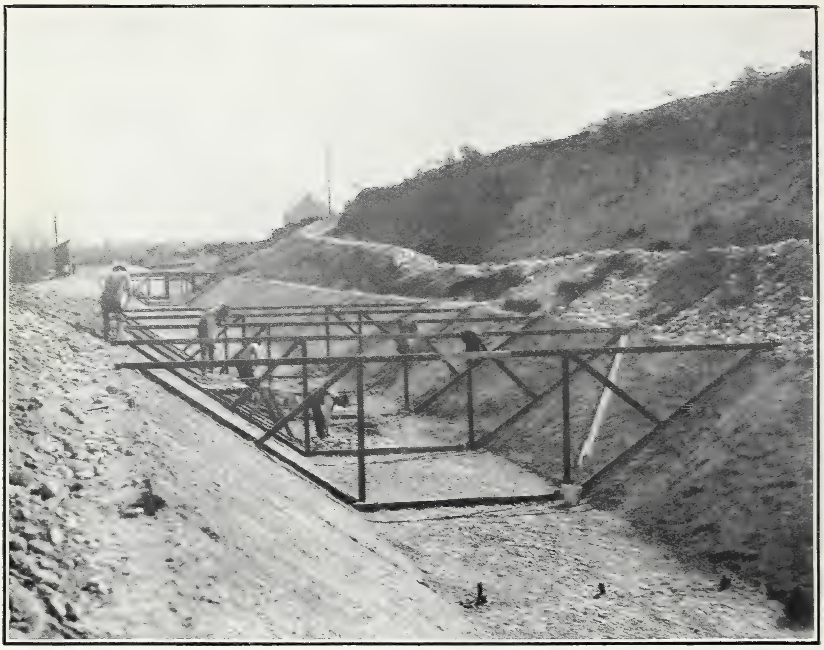


FIG. 1.—TEMPLATES USED IN PREPARING EARTH SECTION FOR CONCRETE LINING, RIDENBAUGH CANAL, BOISE, IDAHO.

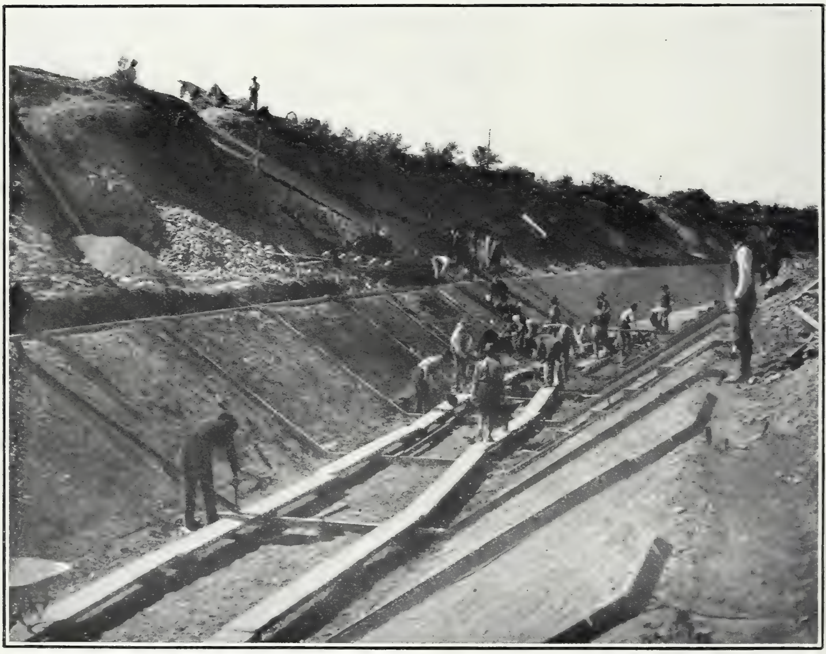


FIG. 2.—FORMS USED IN PLACING CONCRETE FOR LINING, RIDENBAUGH CANAL.

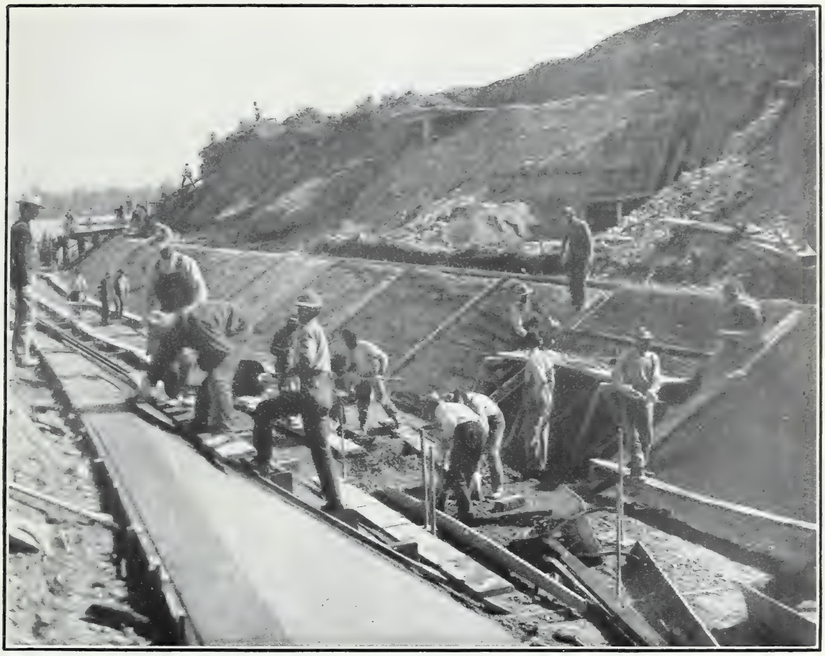


FIG. 1.—LAYING AND SURFACING CONCRETE ON SLOPES, RIDENBAUGH CANAL.

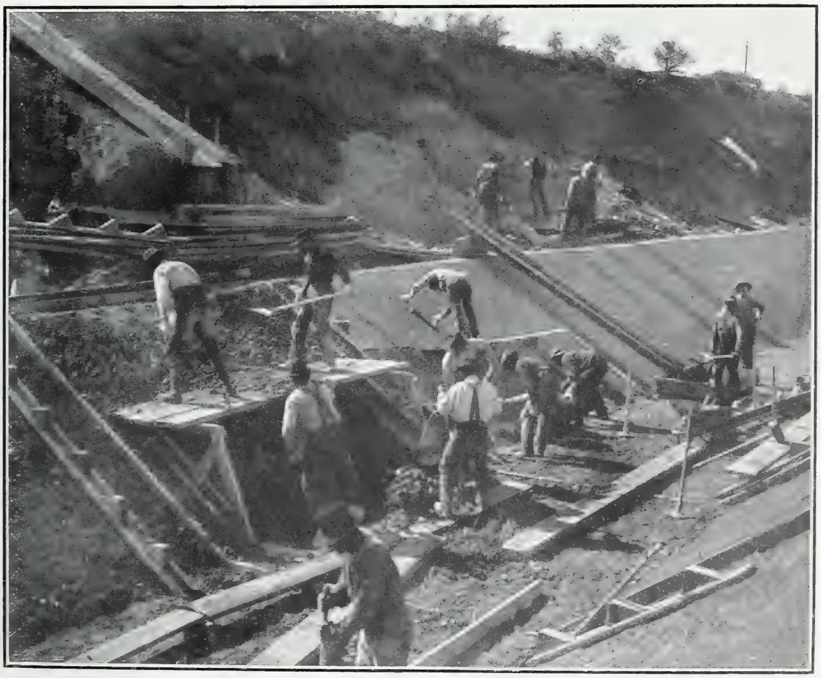


FIG. 2.—METHOD OF DELIVERING CONCRETE FOR SIDE LINING, RIDENBAUGH CANAL.

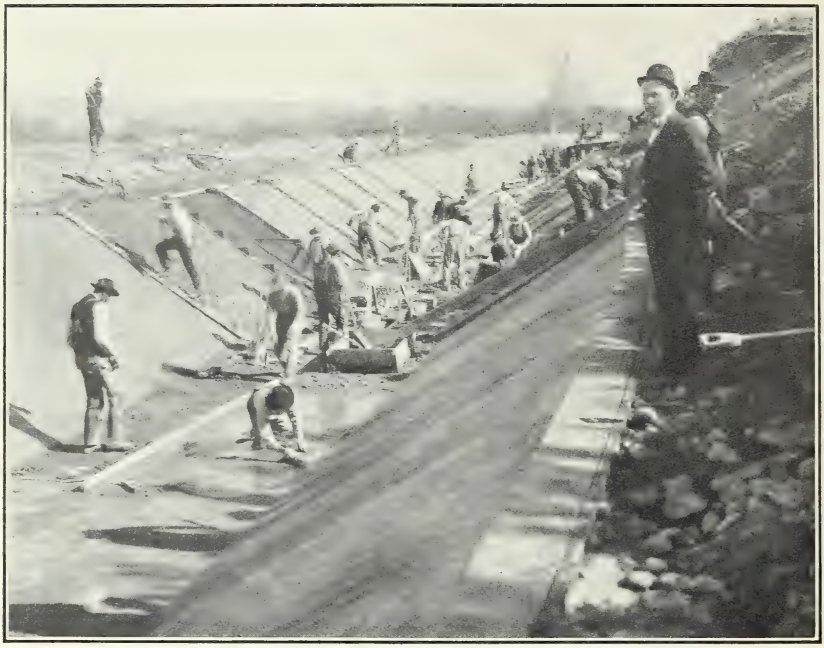


FIG. 1.—METHOD OF LAYING BOTTOM LINING, RIDENBAUGH CANAL, BOISE, IDAHO.

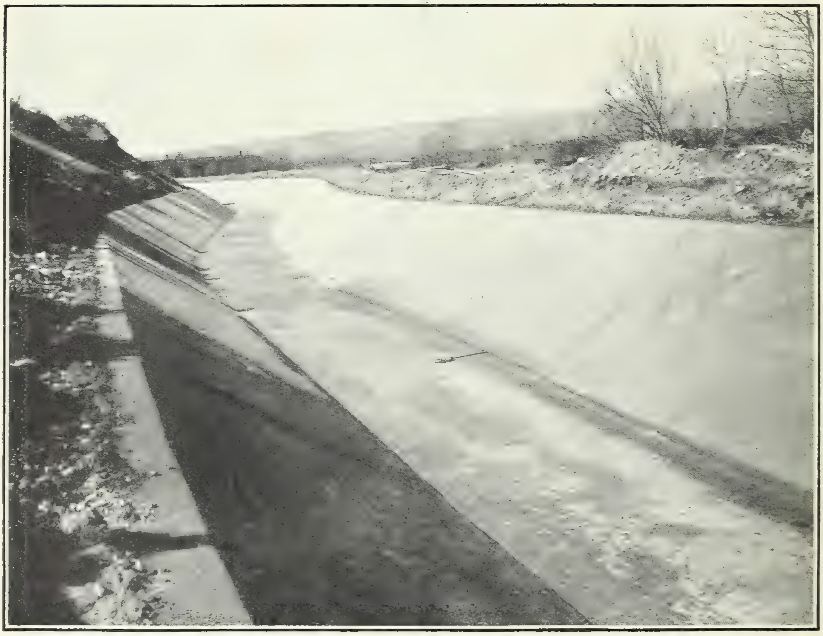


FIG. 2.—A PORTION OF THE COMPLETED LINING, RIDENBAUGH CANAL, BOISE, IDAHO.

THE LOS ANGELES AQUEDUCT, LOS ANGELES, CAL.

About 37 miles (196,402 feet) of canal forming part of this aqueduct is concrete lined. The excavation was made with a steam shovel, and some of the excavation was in very rocky ground. The slopes and bottom of the channel left rough by the steam shovel were brought to a fairly even surface by trimming off the high places, and the low portions were shoveled full of moist earth which was tamped to place. The guideboards set to allow a slab length of 12 feet were held to place by stakes driven into the earth.

In placing the concrete for lining, a platform was built half way up the slope, and in order to reach the upper half of the slope the concrete was handled a second time from this platform. Alternate slabs were first laid and these were brought to surface by the use of a straightedge supported on the guideboards. After this concrete had set and the forms were removed the intermediate slabs were concreted in and brought to a true surface, using the straightedge on the hardened slabs as guides. A ¼-inch plaster coat of 1:2 mixture was finally applied. The bottom lining was afterwards laid continuous and with a curved bottom as shown in figure 15. The work in various stages of construction is shown in Plate XII, figures 1 and 2, and Plates XIII and XIV.

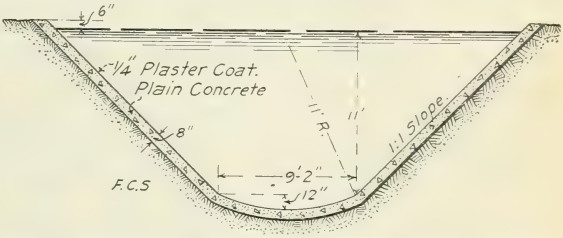


FIG. 15.—Cross section of concrete-lined channel, Los Angeles Aqueduct, Los Angeles, Cal.

This canal was designed to carry 923 second-feet of water at a mean velocity of 4.05 feet per second. The coefficient of friction n was taken at 0.014.

No reinforcement was used, and on most of the work the lining is made of a concrete mixture having 1 part cement to 6 parts sand and gravel, but in some portions a 1:5 mixture was used. A blended mixture of one-half tufa and one-half hydraulic cement was used for all the lining. The total cost of the concrete per cubic yard in place was about $5, and the materials used in a cubic yard of concrete cost about as follows: Cement, $2.60; sand and gravel, $1; and mixing and placing, $1.

RIDENBAUGH CANAL, BOISE, IDAHO.

The 2-mile portion of this canal which is concrete lined is along a gravelly sidehill that had formerly caused large seepage losses and expensive maintenance.

The lining has a 3½-inch base overlaid with a ½-inch top coating of cement mortar hand-troweled to a very smooth and even surface. The canal has a bottom width of 10 feet, 1½ to 1 side slopes, and a vertical depth of 6½ feet. At the top of the lining a 1-foot berm extends back into the bank. When carrying a 6-foot depth of water the canal has a capacity of 615 second-feet.

The lined portion of this canal offers an example of unusual care in construction to obtain a smooth interior. Its curves have been spiraled throughout. The lining is made up of 16-foot sections on tangents and 12-foot sections on curves. The exact shape of the finished section was secured by the use of a template having the same area as the cross section of the finished canal. The methods employed in construction and various details of the work are shown in Plates XV to XVII, inclusive. The concrete was laid continuously. Adjoining slabs were separated by one thickness of tar paper and connected by short lengths of ½-inch steel rods used as dowel pins. The entire surface of the lining was plastered and smoothed with a steel trowel as soon as the concrete had set sufficiently to permit it, and which doubtless accounts for the absence of surface scaling.

No displacements due to pressure, settlement, or buckling are to be found in this lining. The only cracks which have appeared are those at the expansion joints. It has been noticed that in the summer these, found to be about 0.025 to 0.030 inch wide in the morning, are tightly closed by 1 or 2 o'clock in the afternoon.

A brief summary of data on various canal linings is given in Table IV for the purpose of supplementing that contained in the text

TABLE IV.—*Summary of data on various canal linings.*

Name of canal or system and location.	Size of canal.			Length lined.	Thickness of lining.	Mixture used.	Cost of cement per barrel delivered.	Cost of sand and gravel per cubic yard.	Wages per day.	Total cost per square foot of lining.	Remarks.
	Bottom width.	Depth.	Side slopes.								
	Feet.	*Feet.*		*Miles.*	*Inches.*						
Tucson Farms Co., Arizona	2–4¾	3	1–1	2½	3	1:4:4 and 1⅓:4:4	$3.24		$2.00		Reinforced concrete, $14.03 per cu. yd.
Belgo-Canadian Fruitlands Co., British Columbia.	¾–3½	2¾	½–1	4½	2½–3	1:2:4	3.75		2.75 $3.00–4.00	$0.118 .130 .142	See p. 70; data are for laterals only.
Los Angeles Aqueduct, California				37		1:6 and 1:5					Concrete, about $5 per cu. yd. in place.
Modesto Irrigation District, California.	34–44	7–5	2–1	0.43	2⅜–2½						Lining in some of the fills reinforced with No. 6 wire fabric.
Patterson Land & Water Co., California.	4½–7		1½–1		3¼	1:6 or 6½					3-in. concrete plus a ¼-in. 1:2 coat of mortar.
South San Joaquin Irrigation District, California.	11.36	11	¼–1	7	bottom, 4 sides, 4–6	1:3:6					Concrete, $14.50 per cu. yd. in place.
Turlock Irrigation District, California.	40		⅛–1		walls, 4 floor, 6	1:3:5					Length, 365 ft.; reinforced with No. 6 wire mesh and 2½-in. bars; concrete in place, $16 per cu. yd.
New York Canal, U. S. Reclamation Service, Idaho.	40	8	1½–1	6½	4	1:3:6			2.50	.14	Surface painted with 1:2 mortar; cost of lining per lin. ft., $9.64.
North Side Twin Falls Land & Water Co., Idaho.	40–60		1¾–1 and vertical	1.59	earth, 4 rock, 6–8	1:3:6 and 1:6					Concrete cost $16.50 per cu. yd.
Payette-Boise Project, Idaho	40	8+	1½–1	1.82	4	1:3:6			*a* 5.00		Surface 1:2 mortar; laid in cold weather; some heating required; labor for mixing and placing concrete, $2.20 per cu. yd.; entire cost of lining, $9.64 per lin. ft.
Ridenbaugh Canal, Idaho	10	6½	1½–1	2	3½						In addition, a ½-in. coating of cement mortar.
Truckee-Carson Project, No. 1, Nevada.	20		½–1	.95	6	1:3:5	2.55			.166	Does not include riprap backing (Eng. News, Oct. 18, 1906).
Truckee-Carson Project, No. 2, Nevada.	8.9		½–1	1.4	6	1:3:5	2.55			.16	
Central Oregon Irrigation Co., Oregon.						1:4:5					
Umatilla Project, Canal M, Oregon.	4	4	1¼–1	2.35	1½	mortar 1:4	2.40	$0.85	2.40	.062	A 4 by 3 in. curb at the top.
Umatilla Project, Canal L, Oregon.	2	2½	1¼–1	.6	1½	mortar 1:4	2.00	2.75	2.40	.054	
Umatilla Project, Canal T, Oregon.	3	3	1¼–1	1.0	1¾	mortar 1:4	2.25	1.20	2.40	.069	Do.
Umatilla Project, Canal A, Oregon.	15	5	1¼–1	.6	2	mortar 1:4	2.30	1.25	2.40	.071	Side lined only.
Umatilla Project, other canals, Oregon.	1–4	1½–3½	1¼–1	1.7	1½	mortar 1:4	2.85	1.25	2.40	.085	Scattered portions only.

a For 8 hours.

TABLE IV.—*Summary of data on various canal linings*—Continued.

Name of canal or system and location.	Size of canal.			Length lined.	Thickness of lining.	Mixture used.	Cost of cement per barrel delivered.	Cost of sand and gravel per cubic yard.	Wages per day.	Total cost per square foot of lining.	Remarks.
	Bottom width.	Depth.	Side slopes.								
	Feet.	*Feet.*		*Miles.*	*Inches.*						
Medina Valley Irrigation Co., Texas.	....	....	3–1	.45	....	....	....	....	$1.50–1.75	$0.21	Cost includes back fill; see p. 80.
Davis & Weber Counties Canal Co., Utah.	....	....	....	9.5	mostly 4 some 6	1:2:4 and 1:2½:5	....	....	....	....	6-in. drain tiling used below a portion of the lining.
Burbank Power & Water Co., Washington.	....	....	....	.76	....	1:2½:4½	$3.25	1.75	2.25	....	Cost of concrete in place, $12.50 per cu. yd.+7 per cent for engineering.
Hanford Irrigation Co., Washington.	8	....	1½–1	5.6	¾–1½	....	4.52	2.27	....	.051	Water per cu. yd. concrete, $0.39; not first-class construction.
Lower Yakima Irrigation Co., Washington.	11.5	....	1½–1	5	1¾	1:3:4	3.10	....	[b] 2.50	.065	Contract for mixing and laying, $0.025 per sq. ft.
Northern Pacific Irrigation Co., Washington.	3–3.5	2.2–1.5	½–1	4.3	2	1:3:4	3.00	1.75	2.50	.122	Work done in cold weather; heating required.
Yakima Project, U. S. Reclamation Service, Washington.	....	....	....	....	....	....	....	....	....	....	49,494 lin. ft. of canal lined, at $32.05 per cu. yd. of concrete in place, or $7.42 per lin. ft. of lining. Work in rough country.

[a] For 10 hours.

CARE TO BE EXERCISED IN OPERATION.

The durability of concrete lining for canals depends not only on good construction but on the care given it as well. Sudden changes of temperature, such as turning out cold water and exposing a lined channel to a hot sun, damage from roots of trees, damage from stock and storm water, the formation of ice, etc., may be very injurious and destructive to good construction unless proper precautions are taken.

The flow in the Davis and Weber Counties Canal in Utah some years ago had been turned out in the early spring when the water was cold. The effect of a hot sun on the concrete lining caused it to expand and buckle in a few places. The lining had been amply provided with expansion joints, but the wooden cleats used during construction had not been removed. No harm would have resulted if the strips had been removed and the joints filled with asphalt. This instance is mentioned to show how injury may occur through carelessness in construction and operation. In such connection can be seen the benefits arising from the use of a somewhat lean mortar for the finishing coat and thus avoid as much as possible the shearing effect between the base of the lining and the surface coat due to the inequality of their coefficients of expansion.

The growth of trees along or near the banks of a canal may injure a concrete lining by the displacement or breaking of individual slabs. The possibility of such injury may be guarded against during construction by entirely removing or cutting back and deadening the tree growth.

Fencing the right of way is the only remedy against damages caused by stock.

Any storm water which is likely to be discharged into the canal should be bypassed. A cloudburst or heavy rainstorm may so raise the height of water in the canal as to endanger its safety, and the flow from even small volumes of storm water entering a canal is usually destructive to the upper part of the lining by washing away the earth backing.

If it becomes necessary to operate a concrete-lined canal in freezing weather, every precaution should be taken to avoid injury that may arise through the formation of ice. One of the principal rules to be observed is to increase, rather than diminish, the flow prior to the beginning of the ice-forming period. The writer has discussed the operation of canals in winter elsewhere.[1]

The formation of ice in a concrete-lined canal is not necessarily injurious. In such instance the canal should be operated to obtain a condition as mentioned in the preceding paragraph and referred to in the discussion cited. The greater the surface width of the water in the channel at the time the ice is formed the greater will be the tendency for the ice sheet to bulge upward and thus relieve the side thrust. Again, the flatter the side slopes of the channel the greater will be the upward component of force parallel to the lining surface and accordingly the less will be the thrust normal to its surface. Of course there are many reasons for limiting the flatness of the side slopes, but in the design of concrete-lined canals for use in localities subject to low temperatures, and particularly where winter operation is necessary, the benefits resulting from flattened side slopes should not be overlooked.

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[1] U. S. Geol. Survey Water-Supply and Irrig. Paper 43 (1901).

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